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AMERICA IN SPACE: FUTURE VISIONS, CURRENT ISSUES

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

MARCH 13, 2019

Serial No. 116–7

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
35–584PDF WASHINGTON : 2019

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March 13, 2019

AMERICA IN SPACE: FUTURE VISIONS, CURRENT ISSUES

WEDNESDAY, MARCH 13, 2019

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to notice, at 10 a.m., in room 2318 of the Rayburn House Office Building, Hon. Eddie Bernice Johnson [Chairwoman of the Committee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

America in Space: Future Visions, Current Issues

Wednesday, March 13, 2019
10:00 a.m.
2318 Rayburn House Office Building

PURPOSE

On Wednesday, March 13, 2019 the Committee on Science, Space, and Technology will hold a Full Committee hearing titled "*America in Space: Future Visions, Current Issues.*" The purpose of the hearing is to provide big-picture perspectives on the future of the nation's civil space activities, including the roles of civil government and commercial entities, and to identify the key issues for the near term. The Committee will receive expert testimony on visions for science and inspiration, human exploration, and the international environment in which space exploration and utilization is carried out.

WITNESSES

- **Dr. Ellen Stofan** – John and Adrienne Mars Director, Smithsonian National Air and Space Museum, Former NASA Chief Scientist
- **Dr. Peggy A. Whitson** – Technical Consultant and Former Astronaut
- **Mr. Frank Rose** – Senior Fellow, Security and Strategy, The Brookings Institution, Former Assistant Secretary of State

BACKGROUND

Where will America's civil space program be in the next 10, 20 or 30 years? Multiple past advisory reports have considered this question. A sampling of those reports are listed and summarized in the following sections, as is background on how the space science community prioritizes its future goals. The civil space program is increasingly working in partnership with the growing commercial sector to leverage its capabilities. The state of the space economy and workforce also help enable the ability to carry out the nation's future visions for space. In addition, the geopolitical environment and the sustainability of the space environment itself are factors affecting the overall context in which the nation's future space activities and visions will be realized.

Reports on Visions and Future Directions

In 1989, twenty years after the Apollo 11 Moon landing, George H.W. Bush challenged the nation to send humans to Mars and return to the Moon en route to Mars. His Space Exploration Initiative was "a new vision for America in the 21st century." Six visions were to guide the Space Exploration Initiative: knowledge of our universe, advancement in science and engineering, United States leadership, technologies for Earth, commercialization of space, and strengthened U.S. economy. In response to a request by then Vice President Dan Quayle, **America at the Threshold: Report of the Synthesis Group on America's Space Exploration Initiative,** chaired by Lt. Gen. Thomas P. Stafford, USAF (ret.), outlined the rationale for implementing President G.H. Walker Bush's Space Exploration Initiative to send humans to the Moon and Mars and presented architectural options for achieving the initiative. (An architecture, as defined in the report, is "a set of objectives to achieve an overall capability…and the sequential series of missions to implement those objectives.") The architectures presented in the report were designed based on the desired emphasis on science and exploration, human presence, duration on the Moon, and space resource utilization. The report also discussed the supporting technologies, educational outreach, and programmatic actions needed to pursue the exploration goals. The report provided a roadmap for the Space Exploration Initiative and made recommendations for implementing actions.

America's Future in Civil Space: Proceedings of a Workshop[1]. In 2017, the National Academies of Sciences, Engineering, and Medicine convened a workshop to review what had changed, new opportunities, and how to inform implementation since the 2009 National Academies publication, **America's Future in Space: Aligning the Civil Space Program with National Needs[2].** The chair of that study, Gen. Lester Lyles, USAF (ret.), summarized the recommendations of the 2009 report:

- "Space program capabilities should be aligned with high-priority national imperatives.
- NASA and the National Oceanic and Atmospheric Administration (NOAA) should lead the formation of an international satellite-observing architecture capable of monitoring global climate change and its consequences.
- NASA, in cooperation with other agencies and international partners, should continue to lead a program of scientific exploration and discovery.
- NASA should revolutionize its advanced technology development program.
- The government should pursue international cooperation in space as a means to advance U.S. strategic leadership and meet national and mutual international goals.
- NASA should be on the leading edge of actively pursuing human spaceflight."

While the 2017 workshop proceedings did not issue recommendations, key individuals summarized themes of the workshop discussions. Those themes included the view that:

- "The goals for our national civil space efforts from the 2009 America's Future in Space

[1] National Academies of Sciences, Engineering, and Medicine 2017. *America's Future in Civil Space: Proceedings of a Workshop in Brief.* Washington, DC: The National Academies Press. https://doi.org/10.17226/24921.
[2] National Research Council. 2009. *America's Future in Space: Aligning the Civil Space Program with National Needs.* Washington, DC: The National Academies Press. https://doi.org/10.17226/12701.

report are still largely valid today, although the environment in which we pursue those goals has changed.

- ... the public knows little of the actual goals of our nation's space endeavors.
- ... NASA remains a symbol of American leadership at home and around the world and can continue to be a tool of international policy, power, and diplomacy.
- Scientific discovery in our space program is transformational because it changes our collective perception of reality.
- The year 2028 is a key date for ISS [International Space Station] and will drive decisions and actions now, while there was also a strong message from a number of participants that we need to continue to plan for a NASA program that goes beyond ISS and beyond low Earth orbit. ...
- New paradigms will also require the development of a new culture in NASA and the advancement of multigenerational teams while retaining institutional knowledge and expertise.
- The right motivation for partnering with private industry needs to be identified and then policies and incentives need to be established to bring industry into contributing to the public good at the core of the program under consideration. ...
- Among what has stayed the same in recent years is that Mars has remained the horizon goal for exploration. What also has not changed is that NASA has too much on its plate and many constraints.
- What has changed includes new international actors in space—including an impressive space program from China. These new entrants and new industry players and new ways of doing business with established industry provide many new opportunities."

Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration. The 2014 National Academies *Pathways*[3] report concluded that, "There is a consensus in national space policy, international coordination groups, and the public imagination for Mars as a major goal for human space exploration. NASA can sustain a human space exploration program that pursues the horizon goal of a surface landing on Mars with meaningful milestones and simultaneously reasserts U.S. leadership in space while allowing ample opportunity for substantial international collaboration—but only when that program has elements that are built in a logical sequence, and when it can fund a frequency of flights sufficiently high to ensure the maintenance of proficiency among ground personnel, mission controllers, and flight crews." The report also discussed the enduring questions and rationales for human spaceflight, public and stakeholder opinions, a strategic approach to a sustainable program of human spaceflight, and technical analysis and affordability.

NASA's Strategic Direction and the Need for a National Consensus[4], a 2012 report by the National Academies found that "NASA now faces major challenges in nearly all of its primary endeavors—human spaceflight, Earth and space science, and aeronautics. While the agency has undertaken new efforts to procure commercial transportation to resupply the International Space

[3] National Research Council. 2014. *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18801.
[4] National Research Council. 2012. *NASA's Strategic Direction and the Need for a National Consensus*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18248.

Station (ISS) and has also initiated an effort to commercially procure crew transportation as well, the agency currently lacks a means of launching astronauts on a U.S. spacecraft to Earth orbit, where the agency operates the ISS, which was built at considerable time, effort, and expense.

Although gaps in U.S. human spaceflight capability have existed in the past, several other factors, in combination, make this a unique period for NASA. These include a lack of consensus on the next steps in the development of human spaceflight, increasing financial pressures, an aging infrastructure, and the emergence of additional space-capable nations—some friendly, some potentially unfriendly. In addition, U.S. leadership in space science is being threatened by insufficient budgets to carry out the missions identified in the strategic plans (decadal surveys) of the science communities, rising cost of missions, decreasing science budgets, and the collapse of partnerships with the European Space Agency (ESA)— this at a time when others (most notably ESA and China) are mounting increasingly ambitious space programs."

Science Priorities and National Academies Decadal Surveys

Space sciences benefit from centralized, long-term planning because individual facilities and missions require years of development, thousands of personnel, and hundreds of millions or even billions of taxpayer dollars. Since the 1960s, the astronomy community has convened a panel of experts every 10 years to set consensus priorities for the coming decade. These so-called decadal surveys are produced through a multi-year process facilitated by the National Academies of Sciences, Engineering, and Medicine and commissioned by federal agencies. Near the mid-point of each decade, the National Academies convenes expert panels to assess progress being made toward meeting the priority recommendations of the most recent decadal survey. Other disciplines have since followed the astronomy and astrophysics decadal survey process. At present, decadal surveys are carried out for Earth sciences from space, planetary science, solar and space physics, and life and physical sciences in space.

The Space Economy and Workforce

The Space Report issued annually by the Space Foundation[5] is a guide to global space activity and includes details and trends on the space economy, space infrastructure, space products and services, and the workforce. According to *The Space Report 2018*[6], 2017 continued the strong growth in the global space industry that began more than a decade ago. In 2017, global space activity[7] grew 7.4 percent to a total of about $384 billion. Eighty percent of the global space activity is now commercial[8], the biggest sectors of which are direct-to-home television (32%) and launch infrastructure and support systems (31%). World government space budgets grew 14 percent, with India, Italy, the United Kingdom, France, and Germany showing the strongest growth

[5] The Space Foundation, founded in Colorado Springs, CO is a nonprofit entity serving the global space community that is devoted to leading efforts in the awareness of space activities, educational programs, and major industry events.

[6] Background information available at: https://www.thespacereport.org/year/2018

[7] Global space activity includes world government *budgets* and commercial companies' *revenues*.

[8] "Commercial" revenues include the sale of products and services enabled by space assets and the products and services that enable private entities to access and use space.

among the major players[9]. The total U.S. government space budget for 2017 decreased 2.5 percent to $43.3 billion due to decreases in the defense space sector. The U.S. government space budget is split into approximately equal parts civil and defense-related.

In terms of the overall space workforce, while the U.S. private industry space companies employed over 128,000 professionals in 2016, that level was down 1.6 percent from 2015 to 2016 and 25.5 percent over the last decade. As the number of private jobs have decreased, however, wages have been growing in real terms. The average commercial space salary in 2016 was $117,000, more than twice the national average across all industries. NASA's workforce has remained steady from 2016 to 2018, but has declined 8.7 percent since 2000. NASA's workforce is also aged, with 15 percent under age 35 and 35 percent above age 54. Average NASA salaries are high overall, though in real terms they have declined 10 percent since 2011 to $107,000 in 2016, due in large part to a freeze on government salaries in 2011-2013 and only slight increases in 2014 and 2015. Despite the decline in wages, NASA has remained the "best place to work" among large federal agencies for the past six years.

International Cooperation/ Geopolitical Factors

International cooperation in space was a founding tenet of the National Aeronautics and Space Act (P.L. 85-568) that established NASA in 1958.[10] Further, the exploration and use of outer space for peaceful purposes is at the heart of the Outer Space Treaty of 1967 to which the United States is a signatory.[11] NASA has embraced international cooperation in its endeavors and the majority of its science missions involve some level of international contribution and partnership. According to NASA's 2014 publication, **Global Reach: A View of NASA's International Cooperation**[12], NASA has carried out more than 3,000 agreements with over 120 nations and international organizations since its establishment in 1958. Today, NASA maintains hundreds of agreements with international partners. Through its partnerships with other nations, NASA benefits from a faster pace of scientific progress as a result of open access to science mission data and from sharing the costs and risks of space activities.

The 2009 National Academies report, America's Future in Civil Space, stated, "*Exerting a global leadership role in space activities is the best means to ensure that space activities can serve the broader security and economic interests of the nation.*"[13] The U.S.-led International Space Station, an international partnership consisting of the U.S., Russia, Japan, Canada and

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[9] The Italian, British, French, and German budgets include both national space spending and their European Space Agency contributions.

[10] The 7th statement in the Act's declaration of policy and purpose states, "(7) *Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results, thereof;*"

[11] The Outer Space Treaty can be accessed at: https://www.state.gov/t/isn/5181.htm. The preamble to the Articles of the Treaty include: "*Desiring to contribute to broad international co-operation in the scientific as well as the legal aspects of the exploration and use of outer space for peaceful purposes,*

Believing that such co-operation will contribute to the development of mutual understanding and to the strengthening of friendly relations between States and peoples,"

[12] Available at https://www.nasa.gov/connect/ebooks/global_reach.html

[13] National Research Council, *America's Future in Space: Aligning the Civil Space Program with National Needs.* National Academies Press: Washington, D.C., 2009, p. 43.

members of the European Space Agency[14], is often cited as a shining example of American leadership. That partnership has been sustained through periodic geopolitical tensions among partner nations.

China. China is not among the International Space Station partners, though its progress in space activities is significant. China became the third nation to launch a human into space in 2003 and has carried out subsequent human missions, including its first space walk in 2008. In 2011, China launched a space station, Tiangong-1, into orbit. The Chinese lost control of the space station, and in 2018, it reentered Earth's atmosphere and crashed into the Pacific Ocean.[15] In the area of scientific exploration, in December 2018, China became the first nation to successfully land a rover, Chang'e-4, on the far side of the Moon.[16] Further, China has assembled the largest ground-based radio telescope, Five-hundred-meter Aperture Spherical Telescope (FAST), in the world.[17]

According to a report prepared for the **U.S.-China Economic and Security Review Commission, "China Dream, Space Dream: China's Progress in Space Technologies and Implications for the United States,"**[18] China seeks an influential and independent presence on the global front, and space is a means to support this overarching strategy. The report states, "Indeed, China's goal is to become a space power on par with the United States and to foster a space industry that is the equal of those in the United States, Europe, and Russia. China takes a comprehensive, long-term approach to this goal that emphasizes the accrual of the military, economic, and political benefits space can provide."

The Space Environment

Orbital Debris. One of the most significant factors affecting the environment of space and the current and future activities carried out in space is orbital debris, which includes debris fragments, used rocket bodies, and other man-made objects. Orbital debris is hazardous; it can travel through space at up to 17,500 mph such that even a small piece of debris that collides with the International Space Station could be catastrophic.[19] According to NASA, millimeter-sized orbital debris, which are too small to be tracked by U.S. government capabilities, pose the biggest risk to spacecraft operating in low Earth orbit. The Department of Defense's Space Surveillance Network (SSN)

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[14] European Space Agency members: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Slovenia is an Associate Member. Canada takes part in some projects under a cooperation agreement.

[15] Kenneth Chang, "Tiangong-1, China's First Space Station, Crashes Into the Pacific", *New York Times*, April 1, 2018.

[16] Steven Lee Myers, "China's Moon Landing: Lunar Rover Begins its Exploration" *New York Times*, January 3, 2019.

[17] Chris Buckley and Adam Wu, "China Hunts for Scientific Glory, and Aliens, With New Telescope", New York Times, September 26, 2016.

[18] Kevin Pollpeter, Eric Anderson, Jordan Wilson, and Fan Yang, University of California's Institute on Global Conflict and Cooperation, "China Dream, Space Dream: China's Progress in Space Technologies and Implications for the United States" prepared for the U.S.-China Economic and Security Review Commission, 2015. Available at: https://www.uscc.gov/Research/china-dream-space-dream-chinas-progress-space-technologies-and-implications-united-states

[19] National Aeronautics and Space Administration, "Space Debris and Human Spacecraft", September 26, 2013. Accessed at: https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

currently tracks approximately 23,000 objects of about 10 cm or larger in space including active satellites and spacecraft, debris fragments, used rocket bodies, and other debris[20]. Events such as China's anti-satellite test in 2007 created more than 3000 pieces of debris.[21]

NASA was the first agency to develop orbital debris mitigation guidelines. Those guidelines were instrumental in the development of U.S. Government Orbital Debris Mitigation Standard Practices. Other nations have followed suit with their own debris mitigation guidelines, and nations have worked together on consensus guidelines. In 2007, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) adopted a consensus set of space debris mitigation guidelines, which were endorsed by the United Nations in 2008.

[20] Frequently Asked Questions at space-track.org, accessed at https://www.space-track.org/documentation#/faq
[21] National Aeronautics and Space Administration, "Space Debris and Human Spacecraft", September 26, 2013. Accessed at: https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

Chairwoman JOHNSON. Good morning. The hearing will come to order, and, without objection, the Chair is authorized to declare recess at any time. Let me welcome our witnesses this morning, and welcome all of you to the hearing on "America in Space: Future Visions, Current Issues."

I have often said that this Committee is about the future, and I commend you to the words on the wall behind me, "For I dipped into the future, far as human eyes could see, saw the world and all the wonder would be." I cite them, because—like outer space, captured childlike wonder and hope for the future that are shared by young and old. This morning's hearing, "America in Space: Future Visions, Current Issues," allows us to contemplate the visions, the wonder, and the possibilities of our Nation's future in civil space. And I hope we don't lose touch with that sense of wonder as we look ahead.

This year we will celebrate the 50th anniversary of the Apollo moon landing. It was a monumental event in human history. Our astronauts have continuously occupied the Space Station in low Earth orbit for almost 20 years, and carried out research there while learning to live and work in space. Our scientific spacecraft have visited every planet in the solar system, and they continuously monitor our own planet's health. Our commercial space sector is growing, offering innovative capabilities and potential new services.

What will our future in space look like in 10, 20, or 30 years out? Where are we going to be with human exploration in 2050? What would be the discovery of life beyond Earth mean for humanity here on Earth? What will the roles and relationships of government and commercial space actors be? What will our response to the interesting—increasing numbers and capabilities of other nations in space be?

Multiple studies and commissions have wrestled with these and other questions. Today we are fortunate to have renowned leaders in space science, human exploration, and international security to share with us their perspectives. I look forward to hearing their testimonies. I know they will help inform us of our future oversight and legislative activities in the 116th Congress.

A few days ago the Administration released its Fiscal Year 2020 budget proposal. Relative to the Fiscal Year of 2019 enacted appropriations, NASA's (National Aeronautics and Space Administration) budget would be cut, and it would not keep pace with inflation in the outyears. I will have more to say about the budget in the future hearings, but for now I will just note that I'm not sure how much vision fits into a budget that shrinks in real terms each year. If we want America to lead with a visionary and effective space program, we must be willing to commit the resources and funding stability to achieve that.

[The prepared statement of Chairwoman Johnson follows:]

Good morning and welcome. I especially want to welcome our distinguished witnesses.

I have often said that this Committee is about the future, and I commend to you the words on the wall behind me: "For I dipped into the future, far as human eyes could see. Saw the world and all the wonder that would be."

I cite them because they, like outer space, capture the child-like wonder and hope for the future that are shared by young and old.

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If we want America to lead with a visionary and effective space program, we must be willing to commit the resources and funding stability to achieve it.

Thank you, and I yield back.

Chairwoman JOHNSON. I thank you, and at this time I would recognize our Ranking Member, Mr. Lucas, for his opening statement.

Mr. LUCAS. Thank you, Madam Chair, and welcome to the first space hearing of the 116th Congress. And I'd like to welcome back Dr. Babin, the Ranking Member of the Space Subcommittee, and congratulate Representative Kendra Horn, the incoming Chairwoman of the Space Subcommittee. As a fellow Oklahoman, I look forward to working with you and Chairwoman Johnson.

We have a lot of work to do. These are exciting times for the Nation's space enterprise. The investments of the past 2 decades are now coming to fruition. The commercial cargo program continues to deliver valuable supplies to the ISS (International Space Station). The commercial crew program took an important step just last week with SpaceX's successful return. We look forward to Boeing's uncrewed mission in the coming weeks, and crewed missions later this year. We're also in the final stages of developing the Space Launch System (SLS), and Orion crew vehicle that will allow NASA to venture farther into space than ever before.

We're in the early stages of developing technologies necessary to return to the moon, as a stepping stone to Mars and beyond. Our Earth observation and astronomical observatories continue to provide world class science. Our planetary probes and rovers continue to explore the solar system. NASA is also pushing the boundaries of aeronautic research to keep our competitive edge internationally.

Even with all these promising efforts, we also face significant challenges. Schedule delays, cost overruns, and technical errors not only harm individual programs, but also impact the agency as a

whole. Delays to the commercial crew program have already forced NASA to purchase additional seats from Russia. Delays to the Space Launch System and Orion crew vehicle are also having impacts. NASA's recent budget request proposes to launch the Deep Space Gateway and the Europa Clipper mission on commercial launch vehicles for the first time. Getting SLS and Orion on track for exploration mission one and two is critical to the long-term viability of these programs, as they are the systems that will push us farther into the cosmos.

Unfortunately, challenges are not unique to human exploration. The James Webb Space Telescope was originally planned to cost between $1 and $3.5 billion, and launch a decade ago, but now stands to cost roughly $10 billion, and might launch in a couple of years. James Webb is a once-in-a-generation observatory that will reinforce American leadership in space science for decades to come. The delays and overruns will also have impact on NASA for just as long. Other observatories, such as WFIRST (Wide Field Infrared Survey Telescope), important grant funding, and missions outside of the field of astronomy and astrophysics, all end up paying that bill.

Outside of civil space issues, we must also be wary of implementing overly burdensome regulations that push nascent space industries overseas. Companies have choices on where to incorporate, manufacture, and operate their space businesses. If we fail to create a competitive environment here in the U.S., and instead implement draconian regulations on an industry in its infancy, we stand to lose the competitive edge we now possess. Top down space traffic management based on incomplete data, stifling regulations on every activity in space, would be a recipe for disaster.

I hope this Committee will continue to be a leader in proposing creative solutions that enable, rather than stifle, the commercial sector moving forward. But the biggest challenge facing NASA is consistency of purpose. The National Academies called for consistency of purpose in their 2014 report, and more recently the Aerospace Safety Advisory Panel went further, stating, "The lack of consistent commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and most importantly, safety."

Congress has been successful in maintaining a consistency of purpose across Administrations, but the task requires continued diligence. In the 2005, 2008, 2010, and 2017 Authorization Acts, Congress stayed consistent, despite Administrative, I should say numerous Administrative attempts, to veer off course. NASA should build the systems necessary to explore the moon, Mars, and beyond in a stepping stone approach that maintains the multi-mission nature of the agency. I trust the Committee's leadership will maintain this direction, and I look forward to working with them on that goal.

And I yield back, Madam Chairman.

[The prepared statement of Mr. Lucas follows:]

Welcome to the first space hearing of the 116th Congress. I'd like to welcome back Dr. Babin, the Ranking Member on the Space Subcommittee and congratulate Rep. Kendra Horn, the incoming Chairwoman of the Space Subcommittee. As a fellow Oklahoman, I look forward to working with you and Chairwoman Johnson.

We have a lot of work to do. These are exciting times for the nation's space enterprise. The investments of the past two decades are now coming to fruition.

- The Commercial Cargo program continues to deliver valuable supplies to the ISS.
- The Commercial Crew program took an important step just last week with SpaceX's successful return. We look forward to Boeing's uncrewed mission in the coming weeks, and crewed missions later this year.
- We are also in the final stages of developing the Space Launch System and Orion Crew Vehicle that will allow NASA to venture farther into space than ever before.
- We are in the early stages of developing the technologies necessary to return to the Moon as a stepping-stone to Mars and beyond.
- Our Earth observation and astronomical observatories continue to provide world-class science, and our planetary probes and rovers continue to explore the solar system.
- NASA is also pushing the boundaries of aeronautic research to keep our competitive edge internationally.

Even with all these promising efforts, we also face significant challenges. Schedule delays, cost over-runs, and technical errors not only harm individual programs, but also impact the agency as a whole. Delays to the Commercial Crew program have already forced NASA to purchase additional seats from Russia. Delays to the Space Launch System and Orion Crew vehicle are also having impacts. NASA's recent budget request proposes to launch the Deep Space Gateway and the Europa Clipper mission on commercial launch vehicles for the first time. Getting SLS and Orion on track for Exploration Mission 1 and 2 is critical to the long-term viability of these programs, as they are the systems that will push us further into the cosmos.

Unfortunately, challenges are not unique to human exploration. The James Webb Space Telescope was originally planned to cost between $1 and 3.5 billion and launch a decade ago, but now stands to cost roughly $10 billion and *might* launch in a couple of years. JWST is a once-in-a-generation observatory that will reinforce American leadership in space science for decades to come. But delays and over-runs will also have impacts on NASA for just as long. Other observatories like WFIRST, important grant funding, and missions outside of the field of astronomy and astrophysics, all end up paying that bill.

Outside of civil space issues, we must also be wary of implementing overly burdensome regulations that push the nascent space industry overseas. Companies have choices on where to incorporate, manufacture, and operate their space businesses. If we fail to create a competitive environment here in the U.S., and instead implement draconian regulations on an industry in its infancy, we stand to lose the competitive edge we now possess. Top-down space traffic management based on incomplete data, and stifling regulations on every activity in space, would be a recipe for disaster. I hope this Committee will continue to be a leader in proposing creative solutions that enable, rather than stifle, the commercial sector going forward.

But the biggest challenge facing NASA is constancy of purpose. The National Academies called for constancy of purpose in their 2014 report, and more recently, the Aerospace Safety Advisory Panel went further stating. "[t]he lack of consistent commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and-most importantly-safety."

Congress has been successful in maintaining a constancy of purpose across Administrations, but the task requires continued diligence. In the 2005, 2008, 2010, and 2017 Authorization Acts, Congress stayed constant despite numerous Administrations attempts to veer off course. NASA should build the systems necessary to explore the Moon, Mars, and beyond in a stepping stone approach that maintains the multi-mission nature of the agency. I trust the Committee's leadership will maintain that direction, and I look forward to working with them on that goal.

Chairwoman JOHNSON. Thank you, Mr. Lucas. Let me announce that if there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

Now we'll introduce our witnesses.

Our first witness, Dr. Ellen Stofan, the John and Adrienne Mars Director of the Smithsonian National Air and Space Museum. Prior to her current position, Dr. Stofan served as a NASA Chief Scientist, where she advised NASA administrator on science programs and strategic planning. She's also held senior scientist positions at NASA's Jet Propulsion Laboratory, including work on missions ex-

ploring Venus, Earth, Mars, and Saturn. She served as chief scientist for the New Millennium program and principal investigator on the proposed Titan Mare Explorer. Dr. Stofan holds a master's degree and doctorate degrees in geological scientist—sciences from Brown University, and a bachelor's degree from the College of William and Mary.

Our second witness, Dr. Peggy A. Whitson, former NASA astronaut, and currently a space and science consultant and Adjunct Assistant Professor at Rice University. Over her career, she has accrued a cumulative time of over 665 days in space, the most of any U.S. astronaut, most of any woman worldwide, and 8th most all time. Since her first space flight in 2002, Dr. Whitson has completed three separate long-duration missions to the International Space Station. She served as commander twice, and was the first female commander. She has also conducted 10 extra-vehicular activities. Dr. Whitson previously served in other NASA positions, including as the Chief of NASA's Astronaut Office, where she was both the first female, and the first non-military leader to serve in that position. She received her bachelor of science in biology and chemistry from Iowa Wesleyan College, and a doctorate in biochemistry from Rice University.

Our third and final witness is Mr. Frank A. Rose, a Senior Fellow for Security and Strategy in the Foreign Policy Program at The Brookings Institution. His research focuses on nuclear strategy and deterrence, arms control, strategic stability, missile defense, outer space security, and emerging security challenges. Prior to joining Brookings, he served as Principal Director and Chief of Government Relations at The Aerospace Corporation, a federally funded research and development center focused on national security space. Mr. Rose previously served as Assistant Secretary of State for Arms Control, Verification, and Compliance during the Obama Administration. He also held national security staff positions in the U.S. House of Representatives. Mr. Rose received his bachelor's degree in history from American University, and a master's degree in war studies from King's College at the University of London.

Our witnesses should know that each of you will have 5 minutes of spoken testimony. Your written testimony will be included in the record for the hearing. When you all have—when you have completed your spoken testimony, we will begin questions. Each Member will have 5 minutes question—to question the panel. And we now will start with Dr. Stofan.

TESTIMONY OF DR. ELLEN STOFAN, JOHN AND ADRIENNE MARS DIRECTOR, SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM, AND FORMER NASA CHIEF SCIENTIST

Dr. STOFAN. Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity to discuss the future of space science and exploration. As a former Chief Scientist of NASA, and the current John and Adrienne Mars Director of the Smithsonian's National Air and Space Museum, there's no topic I find as exciting or as fundamental to scientific discovery, technological development, and economic growth as this one.

The study of space begins and ends here on Earth. The improvement of life on Earth has been the impetus for, and the guiding principle behind, all space exploration. Why do we explore? What do we hope to gain? What waits for us on the moon, Mars, and beyond? The answer was, is, and always will be found here at home.

Fifty years after we first set foot on the moon, we are entering a new space age, and it is poised to be even more transformational than the first. The commercial, scientific, and security development of the space around Earth has been a priority for decades, and in the next 10 years we will become ever more dependent on our orbital infrastructure to support our way of life here on the ground.

Consider the stunning social, economic, and security implications of the GPS system, now entering its third decade as a public asset. Now apply that scale of transformational change to critical sectors, like energy and agriculture. Just this past week, reports on the impact of saltwater intrusion on coastal farmland, and the devastating effect it has on farmers and their families, illustrated the imminent danger of climate change.

As sea levels rise, and weather events become more extreme, agricultural activities will require sophisticated data from Earth observing satellites, and that is just one of the many sectors that will require space-based intelligence to make essential decisions to keep our economy moving forward as we work to mitigate the effects of climate change. Understanding climate change on Earth is also informed by our studies of planets across the solar system. Comparative studies of planets, from greenhouse gases on Venus, to interior quakes on Mars, or volcanoes on the icy moons of the outer solar system, moves our understanding of Earth's complex environments forward.

But in the next 20 years, our study of worlds beyond our own will yield a new discovery that will tell us even more about our home in the universe. We will discover life elsewhere in space. It will likely begin with fossil evidence on Mars, then simple organisms under the ice on Europa and/or Enceladus. The hydrocarbon seas on Titan could provide proof of life so alien that it redefines our understanding of how it evolved here on Earth, and the possibilities for life in exotic environments beyond our own solar system.

Our solar system is the stepping stone for us to understand the possibilities for life elsewhere in the universe, as our advanced telescopes continue to characterize worlds around other suns. The discovery of extraterrestrial life will be a defining moment in the 21st century, just as the moon landing was in the 20th. But to get there we must invest in missions like the Europa Clipper, Mars sample return, the Webb Telescope, and in human exploration beyond low Earth orbit. We know where to look, and we know how to look. We have the technology to determine if life has evolved elsewhere in the solar system, and can easily do so within the next 2 decades.

In the next 20 to 30 years I hope that humans will have achieved a flourishing presence in the solar system, including a permanent presence on the moon, and a scientific outpost on Mars. Thanks to NASA's ongoing voyages to the Red Planet, we now know more about Mars than any other planet in the solar system, save Earth, and learn more almost daily. Mars remains the horizon goal, according to the National Academy of Sciences, and I believe we can

see the path to that horizon more clearly than ever. The question before us is, are we on the right path to realize this bright future? I'd say the answer is a tentative yes, with opportunities and challenges.

Getting there depends on consistent investment focused where it brings the biggest and most significant return. That includes finding the right balance with the private sector so NASA can do what it does best, big-picture exploration, cutting-edge, academy-level science balanced across astrophysics, heliophysics, Earth science, and planetary science, as prioritized in the Decadal surveys, and aeronautical innovation. It also means inspiring and investing in a diverse, enabled workforce to bring all the creativity and talent of our Nation to the task. This is a priority of the National Air and Space Museum.

As we celebrate the 50th anniversary of Apollo at the museum, we have explored what it took to meet such an audacious challenge as landing on the moon just 8-1/2 years after a young President set the goal. It took a national commitment, steady and reliable funding, and an understanding with giant leaps comes risk, but that risk is what leads to great rewards, with investments in technologies and scientific discoveries than can transform our economy, and keep us at the forefront of the world. The challenges and opportunities of this moment, like those 50 years ago, can lead to amazing, enduring achievements for the benefit of all humankind.

I look forward to your questions.

[The prepared statement of Dr. Stofan follows:]

Written Statement of

Ellen R. Stofan, PhD
John and Adrienne Mars Director
Smithsonian National Air and Space Museum

before the
Committee on Science, Space, and Technology
United States House of Representatives

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity to discuss the future of space science and exploration here today.

As a planetary scientist, former Chief Scientist of NASA, and the current John and Adrienne Mars Director of the Smithsonian's National Air and Space Museum, there is no topic I find as exciting, or as fundamental to scientific discovery, technological development, and economic growth, as this one.

The study of space begins and ends here on Earth. From ground-based observatories to interplanetary probes and human spaceflight, the improvement of life on Earth has been the impetus for, and guiding principle behind, all space exploration. Why do we explore? What do we hope to gain? What waits for us on the Moon, on Mars, and beyond? The answer was, is, and always will be found here at home.

In the nineteen sixties and seventies, the world experienced such a surge in space achievement that one astronaut commented that it was as if a decade of the twenty-first century had fallen backwards into the twentieth. Our world today is largely defined by the social and technological legacy of that era. Now, fifty years after we first set foot on the Moon, we are entering a new space age, and it is poised to be even more transformational than the first.

The commercial, scientific, and security development of the space around Earth has been a priority of space agencies and commercial partners for decades. With the completion of the International Space Station, and countless constellations of satellites, our efforts in Low Earth Orbit are reaching maturity, and in the next ten years, we will become ever more dependent on our orbital infrastructure to support our way of life here on the ground.

Consider the stunning social, economic, and security implications of the GPS system, now entering its third decade as a public asset. Now apply that scale of transformational change to critical sectors like energy and agriculture. Just this past week, reports on the impacts of salt-water intrusion on coastal farmland, and the devastating effects it has on farmers and their families, illustrated the imminent danger of climate change.

As sea levels rise and weather events become more extreme, agricultural activities will require sophisticated data from Earth-observing satellites. And that is just one of many sectors that will require space-based intelligence to make essential decisions to keep our economy moving forward as we work to mitigate the effects of climate change.

Understanding climate change on Earth is also informed by our studies of planets across the solar system. Comparative studies of planets—from greenhouse gasses on Venus to interior quakes on

Mars, or volcanoes on the icy moons of the outer solar system—moves our understanding of Earth's complex environments forward.

But in the next twenty years, our study of worlds beyond our own will yield a new discovery that will tell us tell us even more about our home in the universe. We will discover life elsewhere in space. It will likely begin with fossil evidence of life on Mars, then simple organisms under the ice on Europa and Enceladus. The hydrocarbon seas on Titan could provide proof of life so alien that it redefines our understanding of how it evolved here on Earth, and the possibilities for life in exotic environments beyond our solar system.

The discovery of extraterrestrial life will be a defining moment in the twenty first century, just as the Moon landing was in the twentieth. But to get there, we must invest in deep space missions like the Europa Clipper, Mars 2020, Mars Sample Return, and in human exploration beyond Low Earth Orbit. We know where to look, and we know how to look. We have the technology to determine if life has evolved elsewhere in the solar system, and can easily do so within the next two decades.

At the same time, our powerful telescopes, on the ground and in orbit like the James Webb Space Telescope, will be zeroing in on Earth 2.0. We will never find another place exactly like home, but finding another world in the cosmos with the same kind of biosphere will be a defining moment in our history.

In the next thirty years, I hope that humans will have achieved a flourishing presence in the solar system, including a permanent presence on the Moon, and a scientific outpost on Mars. Thanks to NASA's ongoing voyages to Mars from the Mariners' observations to the Viking landers to our incredibly successful rovers, we now know more about Mars than any other planet in the solar system save Earth, and learn more almost daily.

When we first launched Viking in the 1970s, Mars appeared within our grasp. Today, it remains the "horizon goal" according to the National Academy of Sciences, but I believe we can see the path to that horizon more clearly than ever, and we have been preparing steadily for the journey.

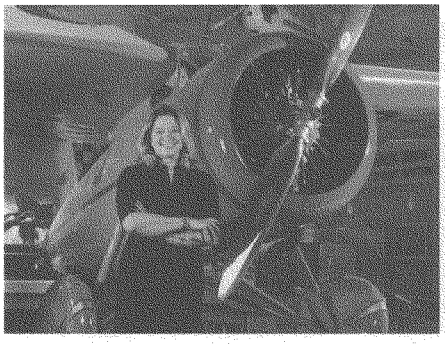
The exciting developments in commercial space operations in Low Earth Orbit are a key foundation to our launch platform for Mars. Having a robust private sector in LEO and eventually the Moon, will let us free government agencies to focus on our next giant leap to Mars.

So, the question before us is are we on the right path to realize this bright future? I'd say the answer is a tentative yes, with opportunities and challenges. Getting there depends on consistent investment focused where it brings the biggest and most significant return.

That includes finding the right balance with the private sector, so NASA can do what it does best, big picture exploration and cutting-edge science, and of course aeronautics. But, it also means investing in fundamental building blocks, beginning with a diverse, enabled workforce to bring all the creativity and talent of our nation to the task- this is what we focus on at the National Air and Space Museum. It includes infrastructure, both in physical technology, and in academy-level science in astrophysics, heliophysics, Earth science and planetary science. That research both guides us where and how to look for answers to the questions we have today, and generates the questions we've never considered that will drive our ongoing exploration.

As we celebrate the 50th anniversary of Apollo, at the Museum we have been spending time thinking about what it took to meet such an audacious challenge as landing humans on the surface of another world just 8 ½ years after a young president set the goal. It took then what it will take now to land humans on Mars and to truly exploit the potential of space- a national commitment, steady and reliable funding, and an understanding that with giant leaps comes risk. But that risk is what leads to great rewards- with investments in technologies that can transform our economy and keep us at the forefront of the world.

The challenges and opportunities of this moment, like those fifty years ago when we first landed on the moon, can lead to amazing, enduring achievements for the benefit of all humankind. I look forward your questions.



Ellen R. Stofan, PhD

John and Adrienne Mars Director, National Air and Space Museum

Dr. Ellen Stofan is the John and Adrienne Mars Director of the Smithsonian's National Air and Space Museum. She comes to the Museum with more than 25 years of experience in space administration and planetary science. Dr. Stofan was previously Chief Scientist at NASA, serving as the principal advisor to the Administrator on science programs and strategic planning.

She held senior scientist positions at NASA's Jet Propulsion Laboratory, including work on missions exploring Venus, Earth, Mars, and Saturn. She served as chief scientist for the New Millennium Program, and principle investigator on the proposed Titan Mare Explorer.

Dr. Stofan holds master's and doctorate degrees in geological sciences from Brown University, and a bachelor's degree from the College of William And Mary. She is an honorary professor at University College London, and was on the board of the College of William & Mary Foundation for 10 years, serving as board chair and co-chair of the development committee as it planned a $1 billion fundraising campaign.

Chairwoman JOHNSON. Thank you very much. Dr. Whitson.

TESTIMONY OF DR. PEGGY A. WHITSON,
TECHNICAL CONSULTANT AND FORMER ASTRONAUT

Dr. WHITSON. Thank you, Chairwoman, and Members of the Subcommittee, for inviting me to give my opinions about space. The ultimate goal must be the establishment of an undeniable United States leadership in the exploration and privately owned development of space. This will reap the direct benefits of technological advancements and economic growth, while bolstering national security. We are well past the flag-planting stage, and it's time to make our ventures into space both commonplace and sustainable. Twice I've had the honor of serving as Commander of the International Space Station, living and working there for 665 days. I can't stress enough the importance of continued expansion of our space presence. It's no longer a matter of national pride. It's our national security, our future, and possibly even our very survival.

I recommend a 10-year plan for a sustainable exploration into space that includes the following. Continued technology development and testing onboard the ISS, prioritizing expertise beneficial for missions to the moon and Mars while we are establishing our presence there. The creation of a deep space infrastructure, such as Lunar Gateway, an orbiting station close to the moon that would facilitate robotic and human surface operations. Further robotic exploration of Mars to better define viable locations for human missions. And, finally, the development of technologies to utilize local resources on the lunar and Mars surfaces. Water, for example, is a source of oxygen, and fuel, and minerals, and other elements. We can't really be sure what we'll find. That's part of the reason we want to go. So this—and inherent in all of this is our continued expansion of international and commercial partnerships.

The ISS in low Earth orbit is an ideal testbed for innovative and redesigned technologies that are lighter-weight, smaller, and more reliable. It's my belief that commercial, private-sector expansion will open up new markets, establish future platforms for research and technology, and the government-led Lunar Gateway would allow us to test and assess such things as solar electric propulsion, lunar robotic exploration, and early stages of human habitation on the moon's surface, while taking advantage of the local resources.

Government-supported expansion to the moon would also serve to stoke the private sector's appetite for further commercialization. For example, providing cargo carriers and lunar landers to the Gateway, and the moon, and beyond, developing and testing other capabilities, such as excavation, drilling, atmosphere collection, in addition to manufacturing and construction. In other words, like Robinson Crusoe, we need to become reasonably self-sufficient up there for any plan to be successful, and, just as importantly, sustainable.

The 20-year and 30-year plans would focus on Mars, and include continued testing for deep space and surface technologies aboard the Gateway and lunar surface, establishment of a Martian infrastructure for continued robotic missions and human surface operations, and utilization of technologies that take advantage of resources on Mars. By 2040 or 50, I envision surface colonization and

research being conducted on Mars. In other words, I can easily imagine people living there, and one of the astounding benefits is that people on Earth will benefit from the technological developments required to go where no one has gone before, and to do so in a way that unites humanity in goals bigger than ourselves as individuals, cultures, or countries.

To lead in space, the United States cannot isolate ourselves. The U.S. Government-led exploration of the cosmos necessarily must include international collaborations. It's all these partnerships that have enabled the International Space Station to be so successful. No matter the winds of politics, intergovernmental ties have sustained a 20-year and counting mission. Astronauts from around the world have lived and worked together successfully, yes, more alike than different. Also critical in our approach, we need to include even more avenues for the participation of our commercial sector, taking advantage of business-savvy people and flexible and innovative approaches.

The biggest challenge I see in future space exploration is enduring stability and consistency. Coming up with a plan, and sticking to it, as we expand our human presence deeper into space, while building the infrastructure to make it sustainable, will lead to greater successes, maximizing taxpayer dollars. Congressionally developed mechanisms to protect the long-range mission with minimal setbacks, and no gaps between election cycles, would be a huge step in assuring a continued U.S. leadership in space. Thank you.

[The prepared statement of Dr. Whitson follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
March 13, 2019

Statement of
Peggy A. Whitson, Ph.D.
before the

House Subcommittee on Space, Science, and Technology
"America in Space: Future Visions, Current Issues"

What is your vision for civil and commercial space over the next 10, 20, and 30 years?

The ultimate goal must be the establishment of an undeniable United States leadership in the exploration and privately-owned development of space. This will reap the direct benefits of technological advancements and economic growth while bolstering national security.

We are well past the flag-planting stage, and it's time we make our ventures into space both commonplace and sustainable. Twice I've had the honor of serving as commander of the International Space Station, living and working up there a total of 665 days. I can't stress enough the importance of the continued expansion of our space presence. It's no longer a matter of national pride. It's our national security, our future, and possibly our very survival.

I recommend a 10-year plan for a sustainable exploration into space that includes the following: 1) Continued technology development and testing on board the Space Station, prioritizing expertise beneficial for missions to the moon and Mars while establishing our presence there. 2) The creation of a deep space infrastructure such as the Lunar Gateway, an orbiting station close to the moon that would facilitate robotic and human surface operations. 3) Further robotic exploration of Mars to better define viable locations for human missions. And finally, the development of technologies to utilize local resources on Lunar and Mars surfaces.

Water for example. And minerals and other elements. We can't really be sure yet what we'll find. Which is all the more reason to go, and inherent in all this is the continued expansion of international and commercial partnerships.

The International Space Station in Low Earth Orbit is ideal for testing new and re-designed life support technologies that are lighter weight, smaller and more reliable. It's my belief that commercial-private sector expansion will open up new markets, and establish future platforms for research and technology, and the government-led Lunar Gateway would allow us to test and assess such things as solar electric propulsion, lunar robotic exploration, the early stages of human habitation on the moon's surface while taking advantage of the local resources. Again, mentioning water. Because with water, we can make fuel and oxygen.

Government-supported expansion to the moon would also serve to stoke the private sector's appetite for further commercialization. For example, providing cargo carriers and lunar landers to the Gateway, the moon and beyond. And developing and testing other capabilities such as excavation, drilling, atmosphere collection, in addition to manufacturing and construction.

In other words, like Robinson Crusoe we need to become reasonably self-sufficient up there for any plan to be successful and enduring.

Examples of Other Worldly Things to Look Forward To:

--Mars Oxygen In Situ Experiment is planned for the Mars 2020 mission to demonstrate the production of oxygen from the Mars atmosphere. Imagine that. Humans could breathe and have fuel without exorbitantly expensive cargo deliveries.

--Using indigenous resources to manufacture replacement parts, complex products, machines and integrated systems.

--Building with local materials produced on the moon and Mars to provide radiation shielding, landing pads, roads, habitats, whatever's needed.

The 20-year and 30-year plans would focus on Mars and include 1) Continued testing for deep space and surface technologies on board the Gateway and Lunar surface, 2)

Establishment of Martian infrastructure for continued robotic missions and human surface operations, and 3) Utilization of technologies that take advantage of resources on Mars.

Projecting ahead to 2040 or 2050, what would give you the most satisfaction in terms of where the space program is? Given your expertise in human exploration, please comment on how human exploration fit into your vision?

By 2040 or 2050, I envision surface colonization and research being conducted on Mars. In other words, I easily can imagine people living there, and one of many astounding benefits is that people on Earth will benefit from the technological developments required to go where no one has before. And do so in a way that unites humanity in goals bigger than ourselves as individuals, cultures or countries.

Space exploration reinforces our similarities, rather than our differences.

To what extent are the civil and commercial space sectors positioned (e.g., technology and research capabilities, workforce and skills, infrastructure, and plans and strategy) to bring your vision to fruition?

If the United States is to continue to lead the way in space exploration, it requires stable funding. Plain and simple.

How do the roles and responsibilities of government, the commercial sector, and international partners affect how the future of civil and commercial space evolves? How, if at all, are those roles changing?

To lead in space, we can't isolate ourselves. The US government-led exploration of the cosmos necessarily must include international collaborations. It's these partnerships that have enabled the International Space Station to be so successful. No matter the winds of politics, intra-governmental ties have sustained a 20-year and counting mission. Astronauts from around the world have lived and worked together successfully, blasting off in rockets, re-entering Earth's atmosphere in crew capsules, spacewalking, fixing things, and talking about our families and personal lives. Yes, more alike than different, and that gives me hope for humanity.

Also critical in our approach, we need to include even more avenues for the participation of our commercial sector, taking advantage of business savvy people and flexible and innovative approaches.

What are the challenges and issues regarding the future of space the Committee and Congress should focus on over the next two years?

The biggest challenge I see in future space exploration is ensuring stability and consistency. Coming up with a plan and sticking to it as we expand human presence deeper into space, while building the infrastructure to make it sustainable will lead to greater successes while maximizing tax payer dollars. Congressionally developed mechanisms to protect the long-range mission, with minimal setbacks between election cycles would be a huge step in assuring the continued US leadership in space.

Biography – Peggy A. Whitson, Ph.D.

Dr. Peggy Whitson is a former NASA astronaut and is currently a space and science consultant and adjunct assistant professor at Rice University. Over her career, she accrued a cumulative time of over 665 days in space, the most of any U.S. astronaut, most of any woman worldwide, and eighth most all-time. Since her first space flight in 2002, Dr. Whitson has completed three separate long-duration missions to the International Space Station, serving as commander twice. She also has conducted 10 Extra-Vehicular Activities, or "space walks," totaling over 60 hours, the third most worldwide.

While at the ISS, Dr. Whitson conducted over 320 scientific experiments, ranging from combustion physics to cancer treatment. She also made significant improvements to operating procedures to allow for more efficient scientific and maintenance activities in the future. Her experiences with NASA also took her underwater as an Aquanaut, when she performed numerous studies as the commander of the 5th NASA Extreme Environment Mission Operations mission.

Dr. Whitson received her Bachelor of Science in Biology and Chemistry from Iowa Wesleyan College in 1981 and a Doctorate in Biochemistry from Rice University in 1986. Soon after at NASA, she continued her biochemical research at the Johnson Space Center. By 1992, Dr. Whitson was named the Project Scientist of the Shuttle-Mir Program, where she integrated US and Russian teams to successfully perform joint research on board the Russian MIR and US Shuttle missions, the start of her extensive record of international coordination. In this time, she also served as Deputy Division Chief of NASA's Medical Science Division, controlling and distributing their $35M budget to advance cardiovascular, neurovestibular, immunological, and biochemical research.

Following her project scientist role, Dr. Whitson was named Co-Chair of the US-Russian Missions Science Working Group in 1995. There, she negotiated with her Russian counterparts on the details of science hardware shipments and on-orbit crew operations until beginning basic astronaut training in 1996.

After two years of leading the Crew Support Office in Russia, where she supervised integration between Russian and U.S. systems, Dr. Whitson trained to be the backup flight engineer for Expedition 3 to the ISS. Then, as part of Expedition 5, launching in June 2002, she was First NASA Science Officer of the ISS for the six-month mission. During this time Dr. Whitson installed multiple truss elements, shields, and other systems to the International Space Station while conducting 21 biochemistry experiments.

From 2003-2005, Dr. Whitson served as Deputy Chief of NASA's Astronaut Office. This role included personnel, facility, and budget planning as well as developing crew training and rotation plans, especially for long-duration missions. This culminated in the forming of a new position, ISS Operations Branch Chief, which she served as in 2005, better supporting international ISS crews in training and in orbit.

For ISS Expedition 16, a six-month mission beginning October, 2010, Dr. Whitson became the first ever female Commander on the International Space Station. This role required extensive international training, planning, and coordination. Dr. Whitson's team assembled a new stage of the ISS, resulting in more than 40% increase in internal volume. All planned objectives of the mission were met, as well as 3.5 times more scientific experiments than were originally planned.

Upon returning in 2008, Dr. Whitson was selected as Chairperson of the Astronaut Selection Board, revamping the selection process in choosing the astronaut class of 2009. Dr. Whitson then became the first female and non-military leader to ever serve as NASA's Chief of the Astronaut Office. In this role, she assessed objectives and crews to ensure the success of ISS and Space Shuttle missions. She oversaw astronaut selection, training, and mission support and served as the U.S. representative for the Multilateral Crew Operations Panel, eventually serving as chair of the international board.

Dr. Whitson continued to select and train astronauts from 2012-2016 until she was selected to join ISS Expedition 50-51-52, launching in November 2016. In these missions she served as Flight Engineer and once more as Commander over the 9.5-month mission. In this time Dr. Whitson performed 40% more scientific investigations than what was originally planned and conducted six more spacewalks, conducting maintenance and upgrades to the station.

Over her career, Dr. Whitson has amassed a number of awards and honors, too many to list in full, but they include…

- 2019 Women in Space Science Award
- TIME Magazine's 2018 Most Influential People in the World
- NASA Outstanding Leadership Medal, 2013
- Aviation Hall of Fame of Texas, San Diego, and Iowa

Chairwoman JOHNSON. Thank you, Dr. Whitson. Mr. Rose.

STATEMENT OF FRANK ROSE,
SENIOR FELLOW, SECURITY AND STRATEGY,
THE BROOKINGS INSTITUTION, AND
FORMER ASSISTANT SECRETARY OF STATE

Mr. ROSE. Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, it is an honor to appear before you to discuss America's future in space. Let me begin by stating that, although I am currently a Senior Fellow at the Brookings Institution, I am presenting this testimony in my personal capacity.

As Members of the Committee can see from my biography, the vast majority of my work has been devoted to the national security and diplomatic aspects of outer space, not civil or commercial space. That said, I have increasingly come to the conclusion that national security, civil, and commercial space have become more intertwined, thus requiring us to address outer space in a comprehensive manner. Indeed, access to outer space is critical to almost everything we do here on Earth.

However, today's outer space environment is evolving rapidly, presenting the United States and other nations with a number of key challenges to the sustainability, safety, stability, and security of the outer space environment. From my perspective, some of the most pressing challenges include the continued growth of orbital debris in various Earth orbits, which represents an ever-increasing threat to both human and robotic space flight, the emergence of mega-constellations of satellites, the deployment of anti-satellite (ASAT) weapons by potential adversaries, and the rise of China as an increasingly prominent outer space actor. Indeed, the space environment has become congested, competitive, and contested. American leadership is key to addressing these growing challenges in outer space, but given the sheer scope of the challenge we face, this is not something that the United States can address alone. It will require active collaboration and cooperation from our international partners.

Let me now provide the Committee with some specific recommendations for addressing these challenges. On orbital debris, we need to ensure a smooth transition of the space traffic management mission from DOD (Department of Defense) to a civilian agency. This will require Congress to pass legislation authorizing the transfer from DOD, or—to Commerce. In my view, passing this legislation should be one of the Committee's top priorities. The United States should also continue to advance international norms in best practices that seek to reduce the growth of orbital debris, and encourage greater cooperation on space situational awareness (SSA).

With regards to the deployment of mega-constellations of satellites, we must ensure that the U.S. Government is organized effectively to manage the rise of these new constellations, and that these constellations are operated in a way that maintains the long-term sustainability of the space environment, especially in low Earth orbit.

The deployment and potential use of anti-satellite weapons will have a direct impact on civil and commercial space systems, there-

fore, it is critical that the Members of this Committee have a comprehensive understanding of the issue. Thus, I recommend the Committee receive the appropriate briefings from the U.S. intelligence community on the evolving anti-satellite threat.

As previously noted, China has emerged as a major international space power, and the United States needs a strategy for managing China's rise in outer space. Therefore, I recommend the Committee direct the Executive Branch to develop a comprehensive strategy for engaging China on space issues. I also recommend continuing the U.S.-China civil space dialog, and re-establishing the U.S.-China space security talks, which were last held in 2016, to ensure we have channels to discuss both areas of potential cooperation, but also places to express our concerns.

Thank you very much for your attention, and I look forward to your questions.

[The prepared statement of Mr. Rose follows:]

Statement of the Honorable Frank A. Rose

Senior Fellow, Security and Strategy
The Brookings Institution

before the

House Committee on Science, Space and Technology
"America in Space: Future Visions, Current Issues"

March 13, 2019

Introduction

Chairwoman Johnson, Ranking Member Lucas, and members of the committee, it is an honor to appear before you to discuss America's future in space. Let me begin by stating that although I am currently a senior fellow at the Brookings Institution, I am presenting this testimony in my in personal capacity. As an independent think tank, the Brookings Institution does not take institutional positions on any issue.

As members of the committee can see from my biography, the vast majority of my work on outer space has been devoted to the national security and diplomatic aspects of outer space, not civil or commercial space. However, based on my experience, I've increasingly come to the conclusion that the national security, civil, and commercial space have become more intertwined, thus requiring us to address outer space in a more integrated manner, and will focus on that interrelationship in my testimony today.

Access to outer space is critical to almost everything we do here on earth. The utilization of outer space helps us warn of natural disasters, facilitate navigation and transportation globally, expand our scientific frontiers, monitor compliance with arms control treaties and agreements, provide global access to financial operations, and scores of other activities worldwide. However, today's outer space environment is evolving rapidly, presenting the United States and other nations with a number of key challenges to the sustainability, safety, stability, and security of the outer space environment.

From my perspective, some of the most pressing challenges include: 1) the continued growth of orbital debris, which represents an ever-increasing threat to both human and robotic space flight; 2) the emergence of mega-constellations of satellites; 3) the continued deployment of anti-satellite weapons by potential adversaries; and 4) the rise of China as an increasingly prominent actor in the civil, commercial, and security space spheres. Indeed, the space environment has become increasingly congested, competitive and contested.

American leadership is key to addressing these growing challenges in outer space. But given the sheer scope of the challenge we face in outer space, this is not something that the United States can address alone: it will require active collaboration and cooperation from our international partners. Indeed, international cooperation must be foundational to the United States' approach to outer space going forward. In my testimony, I will further elaborate on the four challenges I outlined above, and make some specific recommendations as to how the United States can address each of them.

Addressing the Challenge of Orbital Debris

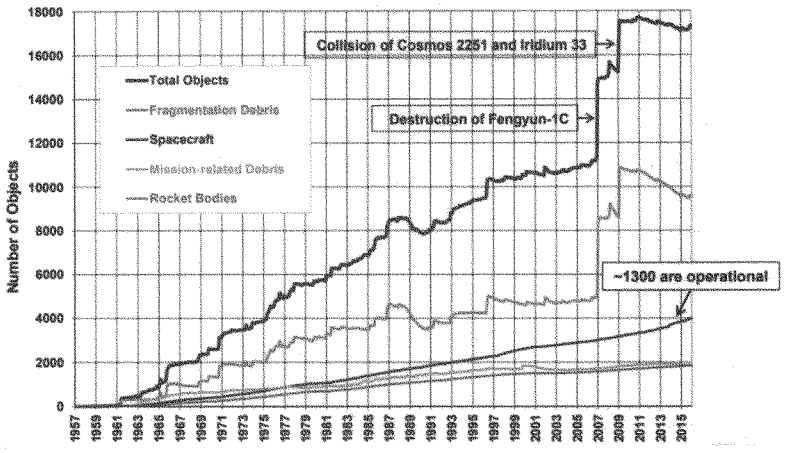
Defining the orbital debris challenge

Decades of space activity have littered Earth's orbit with defunct satellites and pieces of debris. As we continue to increase activities in outer space, the chances of a collision increase. The United States is currently tracking over 20,000 pieces of orbital debris 10 centimeters or larger in various Earth orbits. Approximately 1,800 of these objects are active satellites. Other objects in orbit include: spent rocket bodies, inactive satellites, a wrench, and even a toothbrush! Additionally, as many as 600,000 pieces of orbital debris smaller than 10 centimeters exist that we currently don't have the capability to track, but could still cause significant damage if a collision occurred. Experts warn that the current quantity and density of man-made debris significantly increases the odds of future collisions either as debris damages space systems or as colliding debris creates more space debris.

Because of the high speeds in which these objects travel in space (17,500 miles per hour), even a sub-millimeter piece of debris could cause a problem for human or robotic missions. This serious problem is continually growing as more debris is generated by routine operations as well as by accidents and mishaps such as the 2009 collision between a Russian Cosmos satellite and a commercially-operated Iridium satellite. Other debris is a result of deliberate acts, like China's 2007 destructive test against one of its own satellites. That single test created over 3,000 pieces of debris larger than 10-cm and will stay in low earth orbit for potentially hundreds of years, presenting an ongoing threat to the space systems of all nations, including China itself. Over the past several years there have been hundreds of occasions when debris from China's 2007 anti-satellite test has come close to their own satellites. Indeed, these two events alone are responsible for approximately 1/3 of all the debris in low Earth orbit.

The following chart on the on page 3, prepared by NASA in 2016, illustrates the dramatic growth in the amount of orbital debris since the dawn of the Space Age in 1957. The key question that arises is how does the United States effectively address the continuing threat from orbital debris. From my perspective, the solution will require a mix of technical, regulatory, and diplomatic efforts.

Growth of Orbital Debris 1957-2015[1]



Space situational awareness and space traffic management

Improving space situational awareness (SSA) – the ability to track, characterize, and catalogue objects in outer space – is foundational to address the threat from orbital debris. For over a decade, the U.S. Joint Space Operations Center (JSPOC), located in Vandenberg Air Force Base in California has provided a global public good by helping government and commercial space operators avoid potential collisions in outer space. JSPOC currently publishes a catalog of space objects and warns global space operators, including foreign governments and commercial operators, of potential collisions free of charge.[2] Additionally, over the past several years, the United States, through the U.S. Strategic Command, has negotiated and signed agreements with 16 governments and 68 commercial entities designed to improve SSA sharing.[3]

However, with the emergence of the anti-satellite threat, which I will address in greater detail later in my testimony, there has been an evolving belief in both the Obama and Trump administrations that responsibility for the space traffic management mission (STM) would be

[1] J.-C. Liou, NASA Chief Scientist for Orbital Debris, "Orbital Debris Challenges for Space Operations," March 2016, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160002047.pdf
[2] General John E. Hyten, "Statement Before for the Joint Hearing of the House Strategic Forces Subcommittee and House Space Subcommittee," June 22, 2018.
[3] Ibid.

better performed by a civilian agency, thus allowing the U.S. Department of Defense to focus on its primary mission: deterring, defending, and defeating threats to the United States

Therefore, on June 18, 2018, President Trump signed Space Policy Directive-3 (SPD-3), the National Space Traffic Management Policy.[4] Under SPD-3, responsibility for STM will be transferred from the U.S. Department of Defense to the U.S. Department of Commerce. I support the decision to transfer the STM mission to a civilian agency, as it will allow for the Department of Defense to focus on its core mission, and make it easier for the United States to more effectively cooperate with international and commercial partners.

That said, the transition of the mission from the U.S. Department of Defense to the U.S. Department of Commerce will take time and require significant coordination. If not done in a careful and deliberative manner, it has the potential to disrupt this critical service. Therefore, I would recommend that the committee make ensuring an effective transition of the STM mission to the U.S. Department of Commerce one of its top oversight priorities over the next year.

Domestic regulatory and diplomatic framework

The United States has one of the most comprehensive set of national orbital debris mitigation standards and practices. NASA and the Department of Defense led the effort to establish the U.S. Government Orbital Debris Mitigation Standards Practices, which were approved by the White House in 2001.[5] These guidelines focus on controlling debris released during normal operations; minimizing debris generated by accidental explosions; selecting safe flight profiles and operational configurations; and ensuring post-mission disposal of space structures.[6] The 2006 and 2010 U.S. National Space Policies directed departments and agencies to implement these practices. But not all nations have been as diligent as the United States in developing and implementing effective debris mitigation practices and standards. This makes continued international engagement critical.

One of the most successful diplomatic efforts to date to address the orbital debris challenge has been the U.N. Debris Mitigation Guidelines, approved by the U.N. General Assembly in 2007.[7] The guidelines are based on recommendations initially developed by the Inter-Agency Debris Coordination Committee (IADC), which consists of representatives from the world's major space agencies such as the National Aeronautics and Space Administration (NASA), European Space Agency (ESA), and Russian State Corporation for Space Activities (ROSCOSMOS). The objective of these guidelines is to minimize the creation of man-made debris in Earth's orbit and reduce the threat to human and robotic space flight.

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[4]The White House, Space Policy Directive-3, National Space Traffic Management Policy, June 18, 2018, https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/

[5] J.-C. Liou, NASA Chief Scientist for Orbital Debris, "Orbital Debris Challenges for Space Operations," March 2016, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160002047.pdf.

[6] Ibid.

[7] "Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space," (Vienna: U.N. Office for Outer Space Relations, 2010), http://www.unoosa.org/pdf/publications/st_space_49E.pdf.

The guidelines focus on limiting the amount of debris released during normal operations, reducing the probability of accidental collision in orbit, and avoiding intentional destruction and other harmful activities. While the guidelines themselves are not legally binding in international law, several countries have incorporated the guidelines into their domestic laws and regulations. The guidelines have also established a precedent as to what a responsible space actor does in orbit, and helped develop a strong international norm against conducting debris-generating events in outer space, such as China's 2007 anti-satellite test.

Building on the Debris Mitigation Guidelines, in 2010, the U.N. Committee on Peaceful Uses of Outer Space (COPUOS) began an effort to develop a broader set of voluntary, best practice guidelines to enhance the long-term safety and sustainability of the outer space environment. These draft guidelines were focused on four broad areas, including sustainable space utilization supporting sustainable development on Earth; space debris, space operations, and tools to support space situational awareness (SSA) data-sharing; space weather; and regulatory regimes and guidance for new actors in the space arena.

In 2016, the COPUOS Working Group on Long-Term Sustainability reached agreement in Vienna on an initial set of 12 guidelines. These guidelines were subsequently agreed to by all 84 COPUOS member states and endorsed by the U.N. General Assembly. An additional set of nine more guidelines was agreed to by the Science and Technical Subcommittee and approved in early February 2018; however, the Working Group, was unable to reach consensus on its final report in how best to refer the preamble and guidelines to the General Assembly due to objections from Russia and several other countries.[8]

Managing Mega-Constellations

As the members of this committee know well, the private sector is fundamentally reshaping the outer space environment. One of the most significant areas where they are doing this is the development of "mega constellations" of small satellites. According to press reports, several companies have plans to launch mega-constellations in the coming years. For example, in November 2018, the Federal Communications Commission (FCC) approved a request by Space X "to construct, deploy, and operate a new very-low-Earth constellation of more than 7,000 satellites using V-band frequencies."[9] These satellites will be used to improve broadband communications globally. Other companies around the world have plans to deploy similar satellite constellations as well. While these mega-constellations will improve space-based capabilities, they will also contribute significantly to the congestion of low Earth orbit.

NASA orbital debris experts have highlighted this concern in a recent study on the potential impact of large satellite constellations. According to Jer-Chyi Liou, NASA chief scientist for orbital debris, "Because of the number of spacecraft involved, [these companies] need to pay attention to certain areas to make sure they do not pollute the near-Earth space

[8] United Nations Office of Outer Space Affairs, "Fact Sheet on Long-term Sustainability of Outer Space Activities," http://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html.
[9] Federal Communications Commission, "FCC Boosts Satellite Broadband Connectivity and Competition in the United States," FCC News, November 15, 2018,

environment with significant orbital debris."[10] To address this challenge, NASA experts have recommended ensuring that the satellites in the constellations are de-orbited at the end of their respective service lives.

As these mega-constellations begin to be deployed it will be important that they are done in a way that is fully consistent with debris mitigation policy and standards. The good news is that U.S. regulators are beginning to think through the implications of mega-constellations of satellites on the long-term sustainability of the outer space environment. In their decision[11] approving the SpaceX constellation, the FCC required the company to come back to the commission with updated plan for debris mitigation. The FCC further noted that

> Across the board, we need to prepare for the proliferation of satellites in our higher altitudes. In short, we have work to do. There are two places we can start. First, the FCC has to tackle the growing challenge posed by orbital debris. Today, the risk of debris-generating collusions is reasonably low. But they've already happened—and as more actors participate in the space industry and as more satellites of smaller size that are harder to track are launched, the frequency of these accidents is bound to increase. Unchecked, growing debris in orbit could make some regions of space unusable for decades to come. That is why we need to develop a comprehensive policy to mitigate collision risks and ensure space sustainability.[12]

While this issue has received significant attention of U.S. domestic regulatory agencies, there are questions as to whether foreign governments are devoting the same level of attention to the issue. Therefore, active engagement with international partners should be a priority for the United States.

Emerging Anti-satellite Weapons Threat

While I understand this committee is primarily focused on the civil and commercial aspects of outer space, as I noted earlier, these cannot be separated from the national security concerns, especially the emerging threat from anti-satellite (or ASAT) weapons. Indeed, ASAT weapons -- and the consequences of their use -- could have significant implications for civil and commercial space systems, especially regarding debris generating events.

U.S. Director of National Intelligence Daniel Coats highlighted this during testimony before the Senate Select Committee on Intelligence on January 29, 2019. In his testimony, Coats noted "that China and Russia are training and equipping their military space forces and fielding new anti-satellite (ASAT) weapons to hold US and allies space services at risk, even as they

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[10] Loren Grush, "As Satellite Constellations Grow Larger, NASA is Worried About Orbital Debris," *The Verge*, September 28, 2018, https://www.theverge.com/2018/9/28/17906158/nasa-spacex-oneweb-satellite-large-constellations-orbital-debris.

[11] Federal Communications Commission, Memorandum Opinion, Order and Authorization, March 29, 2018, https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0329/FCC-18-38A1.pdf.

[12] Ibid.

push international agreements on non-weaponization of space."[13] There are a wide number of potential threats to U.S. space assets, including jammers, kinetic energy weapons, cyber, and lasers.[14]

Given the negative impact that ASAT weapons could have on civil and commercial space systems, I would recommend that the committee be briefed by the U.S. intelligence community on this very significant challenge.

Managing China's Rise in Outer Space

Overview of China's space program

Over the past decade, China has emerged as a major international space power. Indeed, earlier this year, China became the first country to land a space probe on the far side of the moon. China's role is outer space is certain to grow significantly in the coming years. According to a December 2018 report by the National Air and Space Intelligence Center,

> China plans to become an international leader in lunar research and exploration with goals to assemble a lunar research station beginning in 2025, perform a crewed Moon landing mission in 2036, and establish and establish a Lunar Research and Development Base around 2050.[15]

China also plans to deploy a rover to Mars by 2020; probe asteroids around 2022; and send a mission to Jupiter around 2029.[16] It has also deployed a number of deep space ground stations around the world, including in Argentina,[17] and is developing its own space station, the Tiangong, is scheduled to become fully operationally around 2022. China's civil space activities are certainly impressive and present multiple opportunities for international collaboration and partnership.

However, as this committee knows well, one of the key challenges to actively engaging China in more robust civil space cooperation is the fact that the Chinese civil space program is controlled by the Chinese military. Therefore, there is a real possibility that any bilateral cooperation could contribute to China's military space programs. In addition to its anti-satellite

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[13] Daniel R. Coats, "Worldwide Threat Assessment of the U.S. Intelligence Committee," January 29, 2019, https://www.odni.gov/index.php/newsroom/congressional-testimonies/item/1947-statement-for-the-record-worldwide-threat-assessment-of-the-us-intelligence-community.

[14] There are a number of recent publicly available assessments of the threat to space assets. Some particularly useful studies include: National Air and Space Intelligence Center, *Competing in Space*, December 2018, https://media.defense.gov/2019/Jan/16/2002080386/-1/-1/1/190115-F-NV711-0002.PDF; and Todd Harrison, *Space Threat Assessment 2018*, Center for Strategic and International Studies, April 2018, https://www.csis.org/analysis/space-threat-assessment-2018

[15] National Air and Space Intelligence Center, *Competing in Space*, December 2018, https://media.defense.gov/2019/Jan/16/2002080386/-1/-1/1/190115-F-NV711-0002.PDF.

[16] Mike Ives, "As America Looks Inward, China Looks to Outer Space," *The New York Times*, May 23, 2018 https://www.nytimes.com/2018/05/23/world/asia/china-space-moon.html.

[17] Lara Seligman, "U.S. Military Warns of Threat From Chinese-Run Space Station in Argentina," *Foreign Policy*, February 9, 2019, https://foreignpolicy.com/2019/02/08/us-military-warns-of-threat-from-chinese-run-space-station-in-argentina/#.

programs, China is also improving its space-based military reconnaissance, remote sensing capabilities, and communications capabilities.[18]

This is not the first time the United States has faced a challenge from a peer competitor in space and also found a way to cooperate with that country on civil space projects. For example, in 1972, the United States and the Soviet Union agreed to an Apollo-Soyuz docking mission, which occurred in 1975. As Michael Krepon of the Stimson Center has written,

> Some feared that this mission would compromise the U.S. space program while providing further rewards to the Soviet program. These anxieties proved to be overdrawn…The Apollo-Soyuz mission established practices of cooperation in space between Washington and Moscow that continue to this day on the international space station.[19]

The key question that the United States must answer with regard to space cooperation with China is as follows: how does it develop a strategy that allows it to cooperate with China on civil space projects, while at same time safeguarding U.S. national security? I would recommend that the United States adopt a strategy that allows limited cooperation on select bilateral civil space projects, pragmatic cooperation on space sustainability issues, combined with a robust dialogue on space security issues and concerns.

U.S.-China civil space cooperation

The United States currently conducts limited bilateral cooperation with China in the civil space arena, primarily focused on aeronautics and Earth science. However, that cooperation is limited by Section 530 of the *Consolidated Appropriations Act for 2019*, which prevents any funds made available by the act from being used for the

> *National Aeronautics and Space Administration (NASA), the Office of Science and Technology Policy (OSTP), or the National Space Council (NSC) to develop, design, plan, promulgate, implement, or execute a bilateral policy, program, order, or contract of any kind to participate, collaborate, or coordinate bilaterally in any way with China or any Chinese-owned company unless such activities are specifically authorized by a law enacted after the date of enactment of this Act.*[20]

But the law does allow for cooperation if NASA, OSTP, and the NSC, after consultation with the Federal Bureau of Investigation, certifies that the cooperation will not harm U.S. national or economic security, and will not involve knowing interactions with any Chinese officials who have been determined by the United States to have direct involvement with violations of human rights. The law requires that any certifications be made to the House and Senate appropriations committees, and the FBI, 30 days prior to initiation of the activity.

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[18] *Competing in Space*

[19] Michael Krepon, "Apollo-Soyuz Redux," *Space News,* January 7, 2013, https://spacenews.com/apollo-soyuz-redux/.

[20] *Consolidated Appropriations Act, 2019,* Public Law No: 116-6, February 15, 2019, https://www.congress.gov/bill/116th-congress/house-joint-resolution/31/text?q=%7B%22search%22%3A%5B%22Consolidated+Appropriations+Act+2019%22%5D%7D&r=5

As I have noted previously, concerns about China's military activities in outer space are valid and I have personally been outspoken about them.[21] That said, there are questions as to whether the current language limiting civil cooperation with China is too restrictive. For example, in a recent press interview, Charles Bolden, former administrator of NASA described the current prohibitions as a "significant legal constraint" and hindrance that should be relaxed of reversed.[22] In the same interview, he argued that the United States should also work to integrate China into the International Space Station.

Based on the concerns raised by former Administrator Bolden and others, I would recommend that the committee review the impact of the current legislative language. China is a major space power and we should find ways to cooperate where practicable, in a manner consistent with the national interests of the United States.

Bilateral diplomatic engagements[23]

During the last two years of the Obama administration, the United States worked to advance a pragmatic discussion with China on space security and sustainability issues, which I participated in actively as assistant secretary of state. For example, in 2015, the United States established a direct link between the U.S. Joint Space Operations Center (JSPOC) and the Beijing Institute for Telecommunications and Tracking (BITT) to provide China more timely conjunction assessment and collision avoidance notifications.[24] Prior to that, all notifications were sent to China via the Chinese Ministry of Foreign Affairs, which was not the most effective way to share these types of notifications.

Furthermore, in May 2016, the United States and China convened the first ever U.S.-China Space Security Talks, which I chaired with my Chinese counterpart from the Ministry of Foreign Affairs.[25] A second meeting of the group was held in December 2016 in Beijing. In addition to the orbital debris issue, the talks addressed measures to build mutual confidence and reduce the risk of miscalculation in outer space. The two sides also established a complementary Civil Space Dialogue, focused on exploring options for increasing bilateral and multilateral civil space cooperation.[26]

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[21] Mike Gruss, "Senior U.S. Official Insists China Tested ASAT Weapon," Space News, August 25, 2014, https://spacenews.com/41676senior-us-official-insists-china-tested-asat-weapon/.
[22] Zhao Huanxin, "Former chief of NASA urges lifting of China ban," *China Daily,* January 14, 2019, http://www.chinadaily.com.cn/a/201901/14/WS5c3bc831a3106c65c34e422f.html
[23] This sections is based on my report "Safeguarding the Heavens: The United States and the Future of Norms of Behavior in Outer Space," *Brookings Policy Brief*, June 2018, https://www.brookings.edu/research/safeguarding-the-heavens-the-united-states-and-the-future-of-norms-of-behavior-in-outer-space/.
[24] Sam Jones, "U.S. and China set up space hotline," *The Financial Times,* November 20, 2015, https://www.ft.com/content/900870f4-8f9f-11e5-a549-b89a1dfede9b.
[25] Mike Gruss, "U.S., China will meet this year to talk space debris," *Space News*, September 22, 2016, http://spacenews.com/u-s-china-will-meet-this-year-to-talk-space-debris/.
[26] "The Second Meeting of the U.S.-China Space Dialogue," U.S. Department of State, October 24, 2016, https://2009-2017.state.gov/r/pa/prs/ps/2016/10/263499.htm.

During President Obama's September 2016 visit to China, the White House released a jointly negotiated fact sheet noting the commitment of China and the United States to work together to reduce orbital debris. The fact sheet states:

> The United States and China recognized that space debris can be catastrophic to satellite and human spaceflight, and that, due to the global dependence on space-based capabilities, the creation of space debris can seriously affect all nations. Therefore, as two Permanent Members of the UN Security Council with major space programs, the United States and China committed to intensify cooperation to address the common challenge of the creation of space debris and to promote cooperation on this issue in the international community.[27]

While the production of a fact sheet in itself is not a major development, it is an example of certain level of bilateral progress that had been made to address space sustainability issues, especially orbital debris.

To date, the Trump administration has conducted limited bilateral engagements with China over outer space issues. On the positive side, the United States and China held the third U.S.-China Civil Space Dialogue on November 30, 2017.[28] Additionally, NASA Administrator James Bridenstine met with Chinese National Space Administrator Zhang Kejian during the International Astronautical Congress in Bremen, Germany on October 1, 2018 to discuss future bilateral cooperation.[29] However, based on publicly available information, it does not appear the United States and China have continued bilateral Space Security Talks that were established in 2016.

Conclusions and Recommendations

- **Space traffic management mission transition**. With the signing of the SPD-3 in June 2018, the space traffic management mission will transfer from the Department of Defense to the Department of Commerce. Ensuring an effective transfer of this mission is critical, and I would recommend that the committee make ensuring that transition one of its most important oversight priorities.

- **International cooperation on space situational awareness.** Though the United States has the best space surveillance network in the world, it can greatly improve its capabilities and effectiveness through cooperation with international partners. Therefore, it will be important to continue and expand the excellent work U.S. Strategic Command has done engaging foreign partners on SSA to date. Indeed, SPD-3 states that "the United States should seek to lead the world in the development of improved SSA data standards and information

[27] "U.S. Fact Sheet for President Obama's Bilateral Meeting with President Xi Jinping," White House, September 3, 2016, https://obamawhitehouse.archives.gov/the-press-office/2016/09/03/us-fact-sheet-president-obamas-bilateral-meeting-president-xi-jinping.

[28] Andrew Jones, "China and US quietly hold third Civil Space Dialogue, discuss exploration plans and cooperation, *GBTimes*, December 11, 2017, https://gbtimes.com/china-and-us-quietly-hold-third-civil-space-dialogue-discuss-exploration-plans-and-cooperation

[29] Jeff Foust, "The challenges to Chinese space cooperation," *Space News*, October 29, 2018, https://spacenews.com/foust-forward-the-challenges-to-chinese-space-cooperation/.

standards." The committee should use its oversight powers to ensure that international cooperation on SSA remains a key priority and receives the necessary resources.

- **Mega-constellations.** The emergence of mega-constellations of satellites in the near future will pose new challenges to our ability to maintain to long-term sustainability of the outer space environment. These new mega-constellations have the potential to provide the world significant benefits, but they must be operated in a way consistent with maintaining the long-term sustainability of key orbits around the Earth. The United States Government has identified the rise of mega-constellations as a significant challenge, but there are questions whether is a truly organized to manage this challenge. Indeed, in its decision authorizing the SpaceX constellation, the FCC noted that it "must coordinate more closely with other federal actors to figure out what our national policies are for this jumble of new space activity. Right now, the National Space Council is considering policy changes to help promote the growth of the commercial space industry…But the FCC should have a seat at this table."[30] Ensuring that are right actors are at the table to address this issue should be a priority for the committee. Additionally, we need to broaden this discussion to include key international actors, as managing the growth of mega-constellations is not an issue that the United States can address alone.

- **Emerging threat from anti-satellite weapons.** One of the most disturbing trends in the outer space environment is the development and deployment of anti-satellite weapons by potential adversaries. The deployment and potential use of anti-satellite and other counter-space capabilities will have a direct impact on civil and commercial space systems. Therefore, I recommend the committee ensure that it has a comprehensive understanding of the issue.

- **International norms of behavior**. As noted previously, outer space is becoming increasingly congested, competitive and contested. The rise of commercial actors, mega-constellations of satellites, and anti-satellite weapons are transforming the outer space environment. The United States cannot solve these problems on its own, it requires international cooperation. Therefore, the committee should encourage the executive branch to actively pursue the development of bilateral and multilateral norms of behavior. And given the increasingly important role that the commercial space sector is playing shaping the future of the space environment, it is critical that they are included in any discussions of norms.

- **Comprehensive strategy for outer space engagement with China**. China is a major actor in outer space and its role will continue to grow in the coming years. Given these facts, the United States needs a comprehensive strategy for engaging China on outer space that addresses the civil, commercial, and national security spheres. I recommend that the committee direct the executive branch to develop comprehensive strategy for engaging China on outer space, that could include steps already taken on bilateral shared interests like space debris mitigation. In the context of such a review, I would also recommend that the

[30] Federal Communications Commission, Memorandum Opinion, Order and Authorization, March 29, 2018, https://transition.fcc.gov/Daily_Releases/DailyBusiness/2018/db0329/FCC-18-38A1.pdf.

committee review the impact and effectiveness of the current legislative restrictions on civil space cooperation with China.

- **Bilateral U.S.-China civil and security space dialogues.** Given the increasing role that China is will play in the civil and security space arena, the United States maintain senior-level civil and security space dialogues to discuss areas for potential cooperation as well as areas of concern. Since taking office, the Trump administration has held one meeting of the U.S.-China Civil Space Dialogue in November 2017. This dialogue should be continued. However, it has not reconvened the Space Security Talks, first held in 2016. I recommend that these security-related space talks be resumed in the near future.

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Frank A. Rose is a senior fellow for security and strategy in the Foreign Policy program at the Brookings Institution. His research focuses on nuclear strategy and deterrence, arms control, strategic stability, missile defense, outer space security, and emerging security challenges. Prior to joining Brookings, from 2017-2018, he served as principal director and chief of government relations at the Aerospace Corporation, a federally-funded research and development center focused on national security space.

From 2014-2017, Rose served as assistant secretary of state for arms control, verification, and compliance. In this position, he was responsible for advising the secretary of state on a wide variety of arms control, strategic policy, verification, and compliance issues. Between 2009-2014, he served as the deputy assistant secretary of state for space and defense policy where he was responsible for key issues related to arms control and defense policy including missile defense, space security, chemical and biological weapons, and conventional arms control.

Prior to joining the State Department in June 2009, Rose held various national security staff positions in the U.S. House of Representatives, including service as a professional staff member on both the House Armed Services Committee and the House Permanent Select Committee on Intelligence. Rose has also held numerous positions within the Office of the Secretary of Defense, including as special assistant to the assistant secretary of defense for strategy and threat reduction, and policy advisor in the Office of the Assistant Secretary of Defense for International Security Policy. He also served as a national security analyst with Science Applications International Corporation and on the staff of U.S. Senator John F. Kerry (D-MA).

Rose received his bachelor's degree in history from American University in 1994 and a master's degree in war studies from Kings' College, University of London in 1999. He is also a recipient of numerous awards including: the Department of Defense Exceptional Public Service Award (2001); the Office of Secretary of Defense Award

for Excellence (2002); the Office of the Secretary of Defense Medal for Exceptional Civilian Service (2005); the State Department Superior Honor Award (2012); and the Ordinul National Serviciul Credincios (Knight) from Romania (2014), in acknowledgement for his role as the lead U.S. negotiator for the 2011 missile defense basing agreement.

Chairwoman JOHNSON. Thank you very much, Mr. Rose. At this point we will begin our first round of questions, and I recognize myself for 5 minutes.

Mr. Rose, I'd like to ask a clarifying question about your written statement. You mentioned that the space traffic management mission would be better performed by a civil agency. You also referred to the Department of Commerce. Is that the civil agency you believe would be best suited for that role, and is this something Congress should evaluate? And I think you just said that.

Mr. ROSE. Thank you for that question, Madam Chairman—Madam Chairwoman. What I would say is this. I fully support transferring the mission from DOD to a civilian agency. We looked at this at the end of the Obama Administration. The general consensus was that this mission should go to the FAA (Federal Aviation Administration), and, honestly, I was a little bit surprised that the Administration decided to move it to Commerce. But I think the fundamental issue is we need to get it right. So I don't have a hard preference one way or the other, but you should ensure, from my perspective, that we do it right, because space situational awareness and space traffic management is foundational to everything else we do in outer space.

Chairwoman JOHNSON. Thank you. Now, of course, in the past FAA has been the major aviation agency. How does Commerce fit into that?

Mr. ROSE. Well, as you know, Commerce does a lot of the licensing, and NOAA (National Oceanic and Atmospheric Administration) runs probably one of the largest satellite constellations in the world. But you are absolutely right, there is the—I believe the Office of Commercial Space Transportation that has a long history of working space issues. And, as I mentioned, at the end of the Obama Administration, we had been looking to the FAA to take the lead on this space traffic management mission.

Chairwoman JOHNSON. Thank you very much. Doctors Whitson and Stofan, as we think about visions for America in space, I'd like to note that the last enacted NASA authorization set Mars as a horizon goal for humans in space. The Act also directed NASA to prepare a human exploration roadmap to get us to Mars. Your written statement noted the importance of having a 10-, 20-, or 30-year plan for our space exploration program. Do such plans exist, and have the priority tasks that need to take place in the International Space Station, and on the moon, been identified in a way that focuses on the horizon goal in sending humans to Mars? Dr. Stofan, you can.

Dr. STOFAN. When I was at NASA, we were working on various architectures to get humans to Mars by—to Mars orbit by 2033, which I've spoken to this Committee a few years ago, so, yes, NASA has been working on architectures. The issue becomes, as the Academy detailed in their Pathways report, there are multiple pathways you can take to get to Mars, and so, in my opinion, you have to use the controlling factor of what is a reasonable budget that NASA would have, what are the technologies that you need that are always building upon each other to get you to the end goal, for example, the Gateway, which allows us to do a lot of the research on life support systems and human health that we need

to do in deep space that will be an extension of what we have been able to accomplish, and will continue to accomplish on the International Space Station.

But I remain, you know, as the Academy said, that Mars is the horizon goal. We need humans on the surface of Mars, breaking open a lot of rocks to find that evidence of past life on Mars. And so, as we develop this architecture, as NASA develops it over the next 10 to 20 years, I think it's very critical to remain focused on what are the critical technologies to invest in that get humans to Mars, because that is the horizon goal. The more paths you go down, the more technologies that are applicable to multiple destinations, the more money you're going to spend, and the further and further Mars will recede into the distance.

Chairwoman JOHNSON. Thank you. Dr. Whitson?

Dr. WHITSON. And I'd like to pile on and add that, in addition, that consistency of purpose and path I think is a good one. I think if we have the appropriate commercial interactions with commercial partners, we can use that path as—to bring in new and innovative ideas, and maybe help us, or assist, and speed us in that planned path to get us to first moon, and then Mars. So I think it's all consistent. I think NASA does have a plan to get there, and—so I'm really excited about our future now. But I do honestly believe it's going to need to be infused with new and innovative ideas that maybe aren't as easy to accomplish strictly within a government path.

Chairwoman JOHNSON. Thank you very much. My time has expired. Mr. Lucas?

Mr. LUCAS. Thank you, Madam Chair. Mr. Rose, let's go back to space situational awareness for a moment. Your testimony recommends the Committee should make ensuring an effective transition to a space traffic management mission to the Department of Commerce one of its top oversight priorities for the next year. The Department of Defense does not conduct, of course, space traffic management, and instead provides a space situational awareness. And I won't quote the Federal statute that's related to, but in this construct, DOD simply provides that data that the private sector can use to inform its operations about coordinating with other space sectors, and consider the other databases offered by commercial providers, international providers.

Last year the Committee passed legislation accomplishing that goal, laid out in your testimony, ironically. You made it clear that you believe Congress should move quickly on this. Can you visit with us for a moment about how we ensure that such a transfer of SSA responsibility from DOC to the Department of Commerce is done without creating new levels of bureaucracy or regulatory burden that just stifle the process for the industries?

Mr. ROSE. Absolutely, sir. I think, you know, we need to make sure that we are consulting very closely with the commercial sector as we move forward. On, for example, many of the norms that I worked on at the State Department, we worked very closely with commercial industry, and they've had a lot of input, so my strong recommendation to the Committee is, as you develop legislation, ensuring that our commercial industry has a say, and has input, will be key.

Mr. LUCAS. Dr. Stofan, flagship missions like James Webb, Hubble, Mars Rover, Europa Clipper are awe-inspiring, and they're costly, and face delays and technical challenges. And these issues, as we've discussed, impact other missions at NASA, require new missions to be deferred, research money to be scaled back. It just re-shuffles the whole deck. And we've heard hours of testimony at this Committee about what went wrong on a variety of these programs, and how we should prevent that in the future. I guess my question to you is, should Congress accept the concept that space is hard, and learn to live with the overruns or delays, or is there something you would recommend to us to help prevent the overruns, or at least mitigate their impact on the rest of the NASA agenda?

Dr. STOFAN. You know, obviously this is an issue that's frustrating to everybody, certainly in the scientific community, and obviously to all of you, but I think the reward that comes from flagship missions is unquestioned. When you look at Hubble, it has rewritten textbooks. It's changed our understanding of the universe. And so, while certainly Hubble also had cost overruns that impacted the program over its 26-year history, I think we've gotten a little bit more than our money's worth out of Hubble, and I strongly believe we will feel the same way about James Webb 10 years from now, when it is giving us planets around other stars, telling us their atmospheric composition, helping us understand where WFIRST and ground-based telescopes, like the giant Magellan Telescope, can focus their next research.

You know, these flagship missions return really important science. I think it's on all of us, and to certainly keep going back to the Academy, to say, are we actually implementing the lessons learned from previous cost overruns? How do we keep those missions in the box, and how do we sometimes make hard decisions about de-scoping those missions in order to keep them closer to the original box that they were put in? But this goes to also an initial problem of how do you cost missions up front so that we bring reasonable cost estimates to you, rather than maybe somewhat optimistic cost estimates that just lead us to problems down the road? So there's multiple issues there.

I think the lessons learned, and implementing those lessons learned, are really critical, but I don't think we should step away from flagship quality science. That's the science that changes the world.

Mr. LUCAS. Fair point. Dr. Whitson, speaking of the big, bold, and the profound, the current budget requests the funding of a 75 metric ton variant of the SLS. Congress directed the agency to develop 130 metric ton vehicle in order to do deep space exploration. Explain to the Committee, if you would, why is a 130 metric ton vehicle necessary? We're getting back to the elementary stuff here, but, why——

Dr. WHITSON. Yes. And——

Mr. LUCAS [continuing]. Do we need the bigger lifter?

Dr. WHITSON. And I actually think that probably we should take that question for the record. I think NASA would have a much more articulate answer than I would on that one.

Mr. LUCAS. OK. Well, let's go one more and see what you think on that. Should Congress fund the continued development of an enhanced upper stage to get to the Block 1B variant of the 105 metric tons, and eventually develop advanced boosters that will enable SLS to lift that 130 metric tons?

Dr. WHITSON. Again, I think that the rocket development and design is much better answered by someone more articulate on that than I am. I'm sorry.

Mr. LUCAS. Well, just from a layman's perspective, if we're going to go way out there, we have to throw big things out there, right?

Dr. WHITSON. Absolutely. We——

Mr. LUCAS. So if we're developing resources to throw smaller things, we're either going to have to send a lot more rockets——

Dr. WHITSON. Exactly.

Mr. LUCAS [continuing]. Package products, or we develop the bigger boosters to put the big piece up in one chunk. Fair statement?

Dr. WHITSON. That is absolutely correct.

Mr. LUCAS. And the perspective of the Committee is let's go, and go hard, it's been in the past, anyway, as opposed to piecemeal. I think I made my point.

Dr. WHITSON. Yes. And there's a lot of risk. With multiple missions, you take lots of risk. You pile your risk more into one vehicle with a bigger one, but I think there, you know, the chances of getting multiple launches is much harder when it—when you're talking—trying to scale it back into a finite number of years.

Mr. LUCAS. Thank you, Doctor. Yield back, Madam Chair.

Chairwoman JOHNSON. Thank you, Mr. Lucas. Ms. Horn.

Ms. HORN. Thank you, Madam Chair, and thank you to all of our witnesses. I would like to start circling back on the debris issue with Mr. Rose, if we could. Looking at your testimony, and the fact that there are now more than 600,000 pieces of orbital debris that we're contending with, can you speak just very briefly about how dire the situation is before right—we dive into—how to address it?

Mr. ROSE. It is not good, and it's getting worse every year. Now, we can track right now about 20,000 pieces of debris larger than 10 centimeters. As you mentioned, ma'am, there are probably about 600,000 that we cannot track, though that will improve this year with the space fence, but this is a serious problem that we need to address, because it is getting worse.

Ms. HORN. Thank you. And, to follow on that, in the conversation and distinction between traffic management and situational awareness, I would like to hear you speak a little bit more about—my concern is losing capabilities in any sort of transition about—what would be needed to move from a situational awareness, and what's the benefit of transitioning out of a DOD, and what kind of resources would be required to effectively do that?

Mr. ROSE. Well, the benefit about transitioning out of DOD is this. DOD needs to be focused on the anti-satellite threat, but, as you rightly note, most, or—if not—yes, I would say most of our capability, from sensors to expertises there, though NASA and other organizations have it. The fundamental point we need to do is make sure we do this in a deliberate manner, and that the transition includes all the key players, whether it be from Commerce, NASA, DOD. So that's my kind of plea to the Committee, is use

your oversight powers to make sure we're doing it the right way, because we can't afford to get this wrong.

Ms. HORN. Thank you. That's part of my concern. I want to transition next to workforce issues. The budget that was just proposed, there are two things, there's the age of the NASA workforce, and then there's the pipeline. So, with respect to the age of the NASA workforce and the pipeline, I want to start with the STEM (science, technology, engineering, and mathematics) programs that the current budget proposes to cut. And, Dr. Stofan and Dr. Whitson, you both, in your testimony, have addressed that. So I wanted to ask you both briefly, what message does this send, and what impact does a cut to STEM programs have to the pipeline of the NASA workforce?

Dr. WHITSON. I really think it's important for us to be educating our young people, and giving them the motivation and the desire to be part of this technology development that we want to happen for our own country, and so I find it difficult to say that we shouldn't do any of it. I know that NASA, by inspiration alone, will continue that, but I do think there should be mechanisms that exist to definitely beef up our young group of future engineers and astronauts to support our future programs. Otherwise, we will be at a huge disadvantage compared to the other countries.

Dr. STOFAN. When I go out and talk to the aviation and aerospace industry, what I hear from them are huge concerns about future workforce. And when you have educational programs like those at NASA, like those that we have at the Smithsonian, that undergo rigorous evaluation—they're—these are programs that are shown to have benefit. They reach, you know, hundreds of thousands, if not millions, of kids around this country, and inspire them to go into STEM careers. They don't always end up at, you know, as NASA astronauts, but they may become civil engineers, or doctors, and go out and contribute.

So I think these programs are critically important because we know it's a pipeline issue, especially for women, and all people of color, that reaching those kids, keeping them in the pipeline, is critically important.

Ms. HORN. Thank you, Madam Chair. I have many more questions, but I'm running out of time, so thank you very much to all the witnesses. I turn the mic back over. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Weber.

Mr. WEBER. Thank you, ma'am. Dr. Stofan, in your discussion with Ranking Member Lucas, you made a couple of comments about the reward from flagship missions should override the disappointments, or something to that extent. Do you remember that? Is that fairly accurate?

Dr. STOFAN. Yes. Frankly, it's a really tough thing, so believe me, this is not an easy thing to say. When you look at the, you know, when you're going through the Curiosity overruns, as I did, or, you know, again, the Hubble overruns—I was at headquarters when we were working on Hubble—or on James Webb, trying to keep it in the box, you know, you don't want those overruns to occur. And I think, again, that diligence in this is extremely important, and staying on top of these missions, trying to keep them in the box, is something that we should try to do. I don't want to be, certainly,

cavalier about it, but those missions change our views of the universe——

Mr. WEBER. Well, sure——

Dr. STOFAN [continuing]. And our solar system.

Mr. WEBER [continuing]. And I appreciated your comments on that, and I think you're on track. My question is, who is categorizing those, as you call them, flagship missions versus kind of the busts, if you will? Who categorizes that, who keeps track of those, what's the ratio, and how do we learn those lessons, and implement those lessons?

Dr. STOFAN. Well, I'll take that from a couple different points of view. Obviously, as you well know, it's the Decadal survey that's done by the Academy that prioritize. And certainly, for example, the Planetary Science Decadal, which I've been involved in the last two Planetary Science Decadals, the Decadals actually recommend, here are missions that we think should be priorities in the flagship class, so much larger missions, harder to implement. And then they also make recommendations on smaller-scale missions. And, for example, the last Planetary Decadal went into great detail about how they thought the tradeoff should be made if budgets were more constrained than previously thought, which that was great advice that came from the Academy to NASA on how to make those decisions.

NASA itself goes through a very rigorous lessons learned process. For example, I was there when we were looking at the lessons learned from overruns from Curiosity.

Mr. WEBER. Let me interrupt, if I can. Is there a person that actually is in charge of tracking this?

Dr. STOFAN. I'd have to take that question for the record. That'd be a better question for NASA. I think it comes out of the Office of the Chief Engineer, but I'm not positive, so I should take that for the record.

Mr. WEBER. Right. Well, thank you for that because, you know, we want to be able to track that. The Ranking Member had some great questions about the size of the delivery platform, for example. Was that a flagship mission? Obviously it was. Was it a success? Obviously it was. But if we had gone bigger, you know, I'm from Texas, where bigger is better, and had we gone bigger, would it have been better, and why didn't we do that, and who assesses that, and gives us that assessment? Do we know that, or is that the same person—you're going to have to get back with us on who that is, what department that is?

Dr. STOFAN. Yes, obviously—and the Space Science Directorate at NASA is responsible for finally evaluating missions, the final design of missions, but they are reviewed externally within the agency.

Mr. WEBER. What does that cycle look like, in length of time? Does it take 1 year, 2 years? How quickly do we come to that conclusion?

Dr. STOFAN. Usually you go through a series—what are called key decision points, or KDPs. And so by the time, I think, you get to—I'm going to screw this up. It's KDP-B, I think, where the—or maybe KDP-C, where the price is finalized. So it's years of studies, of assessments, of external review boards that look at the costs and

try to understand what the mission—how it's scoped. But, again, NASA can give you a much better answer.

Mr. WEBER. OK. And I appreciate that. So, in the last minute left, this is a question for all of you, and Dr.—Mr. Rose, I'll start with you, so you don't feel left out, and Dr. Whitson, hopefully get to you. What should our priorities and strategies be for the next 5 years and next 10 years in order to regain access to low Earth orbit and maintain the development of exploration systems? What should our priorities and strategies be? Mr. Rose?

Mr. ROSE. Addressing the orbital debris problem.

Mr. WEBER. I figured you would say that. OK.

Dr. WHITSON. OK. And I would say that we need to continue research that prioritized on ISS, but prioritized for moon missions. For instance, we need to do things like make the life support systems much more compact. Also, there's missions like the—the Mars 2020 is going to test the ability to take carbon dioxide from the Martian atmosphere and make it into oxygen, and that's great for breathing and fuel. And testing those types of capabilities are going to be the things that enable a sustainable future in space.

Mr. WEBER. All right. And I appreciate that, and, Madam Chair, I yield back with 2 seconds.

Chairwoman JOHNSON. Thank you very much. Ms. Bonamici.

Ms. BONAMICI. Thank you, Chairwoman Johnson, and Ranking Member Lucas, and thank you to all of our witnesses. We've had many conversations in this Committee over the years about the role that NASA plays in sparking the imagination of the next generation of students, especially students to pursue careers in science and astronomy. I also know, as Member of the Education Committee, where I'm going back and forth this morning, talking about college affordability, which is directly related to the workforce issues we're talking about, that we need critical thinkers, and we need people who are inventive and entrepreneurial.

So I am the co-Chair of the bipartisan STEAM Caucus with Representative Stefanik from New York, where we are identifying ways to integrate the arts and design into STEM learning to engage more students, but also to make sure that students are getting a well-rounded education. Former NASA astronaut Cady Coleman, who's also a musician, she did this great flute duet from the ISS with her flute duet partner on Earth, which I thought was pretty amazing, in 2011, I believe that was.

Dr. Stofan, the ingenuity of our workforce will also define our response to global problems like climate change. In your testimony you discuss how our understanding of climate change on Earth is informed by comparative studies of planets across the solar system, so how can we leverage information from Earth-observing satellites to strengthen our understanding of climate change, and to identify successful adaptation and mitigation strategies?

Dr. STOFAN. You know, for our Earth-observing satellites, the most important thing is continuity, so—because trying to extend, you know, trying to extend the models, trying to always strengthen our modeling capability for climate change, we critically rely on a long-term data set that's consistent. And so, supporting the Earth observing satellites, making sure those satellites continue to go forward, I think is critically important to give decisionmakers around

the country the data that they need to be able to make critical decisions. And so it's not just data for the scientists, it's how do you change that data into actionable information that can be used by policymakers. And I just think it's critical that that continue to be supported.

Ms. BONAMICI. Thank you, I appreciate that. I'm also the co-Chair of the House Oceans Caucus, and we've been working on marine debris. Every minute the equivalent of a garbage truck full of plastic is dumped into the oceans. But our oceans are not the only place where there's debris. Of course, we have non-functioning spacecraft, defunct satellites, and, as you mentioned in your testimony, Mr. Rose, even a toothbrush accumulated in our Earth's orbit. So, according to NASA, that debris can travel at speeds up to 17,500 miles per hour. Is that right? That seems like a problem. In the event of a collision, for example, with the ISS, the impact could be catastrophic. So, Mr. Rose, is there any hope to meaningfully address orbital debris, and how can we mitigate in the future?

Mr. ROSE. A couple of things. One, we have to stop the debris environment from getting worse, specifically not doing another ASAT test, like China did in 2007. We need to improve space situational awareness to prevent future collisions like the Iridium/Cosmos event, and we need to enhance best practices internationally. The United States has very, very good domestic legislation. Not all of our international partners do. And then, finally, looking over the horizon, there's this whole issue of active debris removal. Very interesting technology, but we need to be careful because one person's debris removal system can be another person's anti-satellite weapon. But the bottom line is we need to address it, and we need to have a comprehensive approach.

Ms. BONAMICI. Thank you. And also, Dr. Stofan, one of the most commonly cited benefits of human exploration, basic scientific research in space, is the benefits from derived research, and, according to NASA, more than 2,000 NASA spinoff technologies have been documented. So what would you say to people who submit that we should, rather than spend money on human exploration, or astrophysics, or planetary science, we should spend it in other areas? What's the best response to that?

Dr. STOFAN. You know, the spinoffs that have come from NASA are so comprehensive, from the nutritional supplement that's found in over 90 percent of baby formulas that started as a supplement for astronauts on the International Space Station, the water purification system on the Space Station that's now—there's a portable form of it that's taken into disaster areas around the world. The work that is done every day at NASA, whether it's in aeronautics, or space science, or up on the International Space Station, has direct and practical benefits here on Earth. And, you know, it—I think people just don't realize how much NASA technology—literally goes from ski boots to the shingles on your roof.

And so the fact that when you invest in something like going to Mars, when you try to do really difficult things, we certainly saw that from the Apollo program, it——

Ms. BONAMICI. Right.

Dr. STOFAN [continuing]. Returned benefits in spades right here—back here on Earth, and that will improve——

Ms. BONAMICI. Thank you.

Dr. STOFAN [continuing]. Going to Mars.

Ms. BONAMICI. If I had more time, I would ask you all whose job it is to convey that, but I don't, so I yield back. Thank you, Madam——

Chairwoman JOHNSON. Thank you very much. Mr. Gonzalez.

Mr. GONZALEZ. Thank you, Madam Chair, and Ranking Member, for holding this hearing today, and also a big thank you to our witnesses for your service to our country, and for all the work that you put into this hearing. I have the honor of representing northeast Ohio, which is home to the NASA Glenn Research Center, a truly magnificent research center. It employs more than 3,000 scientists, engineers, and technicians. In a recent trip to the center, I spoke with Director Janet Kavandi, also a former astronaut, and an amazing woman—I mean, we had just the greatest conversation. But, in any event—about the incredible aeronautic and space research conducted at Glenn every day, and how NASA Glenn is pioneering the next generation of space and air travel.

So Dr. Stofan first, can you just provide a brief overview of just how important our research centers are to the NASA program in making sure that we do, in fact, stay on the competitive edge of space and aeronautics research?

Dr. STOFAN. You know, you touched my heart there because my father is a former director of the Glenn Research Center, and I actually grew up literally at then Lewis Research Center, so I am particularly passionate about centers like Langley, like Lewis, like Ames, our NASA centers around the country that are doing cutting-edge research every day in aeronautics, in technology, in science. And it's that fundamental basic research that helps move our aviation industry forward, that helps move all kinds of, you know, create small businesses around this country from spinoffs that come out of the technology.

So these research centers, I think, are critical to economic growth, especially in those areas in which they sit, where they have strong relationships with local universities, local businesses. Incredibly important.

Mr. GONZALEZ. Thank you. And I share the sentiment of my colleague, who just mentioned seeing all of the spinoffs that come off of NASA research technology, and just how important it's been to our economy writ large. It's not, you know, I think we think of NASA as, you know, going to the moon, or going to Mars, or what have you, but it's really fundamental to many technologies in our economy, and just think it's imperative that we make sure that the funding's kept in line with the demands that we have.

So, switching gears to Mr. Rose, in your testimony you state that China has emerged as a major international space power, and it's certain to grow significantly in the coming years. To me, the U.S.-China relationship will come to define the 21st century of U.S. foreign policy. While I believe we must work to build a stronger relationship with China, I also believe that everything we do with China must be approached with an abundance of caution. So could you talk specifically about the connection between Chinese space travel, and the Chinese military, and the national security implications to our country?

Mr. ROSE. Sir, the Chinese space program is a wholly owned subsidiary of the People's Liberation Army, and there's been no one more outspoken in the U.S. Government, or outside the government now, about concerns with China's anti-satellite program. But at the same time, we need to work with China on things like orbital debris mitigation. That's why I think we need a comprehensive strategy for dealing with China that links commercial, civil, and national security space. We didn't have one in the Obama Administration, we don't have one now. I think we need one.

Mr. GONZALEZ. Yes. I share your concern. And then you also talked about—and kind of to double down on that, the need for greater cooperation. Can you talk about a framework that you think would be effective in supporting that? I mean, I'm trying to just wrap my head around—how would we even approach this? Because if they're a fully owned subsidiary of the military, it's hard to even see a path forward.

Mr. ROSE. Now, I agree with you, but I think we need to do is—one of the fundamental problems is there's absolutely no trust between the U.S. and China right now on outer space. Scott Pace, the Executive Director of the National Space Council, said that in an article a couple of weeks ago. But we need to build some trust. Now, we were able to do that on the issue of debris. I talk about that in my testimony. What I would recommend is kind of the following. One, find a couple of specific projects that we can do on the civil side that will not undermine national security, but build some trust, number one. Number two, we have to have both a civil dialog to talk about the sustainability issues, but we also need to recreate the space security talks. We held those first ones in the Obama Administration. Unfortunately, they have not been re-established. I think we need to do that to provide the venue to express our concerns about China's activities.

Mr. GONZALEZ. Thank you, and I yield back.

Chairwoman JOHNSON. Thank you very much. Ms. Wexton.

Ms. WEXTON. Thank you, Madam Chair, and thank you to the witnesses for being here today. Following up on the questions about China and other countries, Mr. Rose, can you speak to what other countries have done with regard to building out their space exploration, or their space infrastructure, and what impact that's having on U.S. leadership in that area?

Mr. ROSE. In the context of China, but—or as a whole?

Ms. WEXTON. On the whole, but also with China.

Mr. ROSE. Well, one of the things that I'm concerned about in the context of China is that many of our allies and partners, to include Italy, are moving forward with cooperation with regard—with China, and my concern is if we don't lead, we will cede that space to China. To a certain extent, we've done that over the last couple of decades. I think American leadership is key, and if the United States does not provide leadership on space exploration, I assure you the Chinese are there, and willing to do it. They actually are using space as a key element of their foreign policy, not unlike how we have handled space. But my bottom line is this. If we do not lead, China will.

Ms. WEXTON. Very good, thank you. Now, I'm from Virginia, and we have the Mid-Atlantic Regional Spaceport, and NASA Wallops,

a number of NASA facilities. Now, Dr. Stofan, and maybe Dr. Whitson you know the answer to this as well, based on your experiences, can you speak to the relationship between civil space and military enterprise, and whether there's any conflict between those two?

Dr. STOFAN. I don't think there's, you know, certainly in the context of the museum, we tell the story about the fact that military space has been there, you know, since we started with space 60 years ago, when NASA was founded, there has been a military space program. We tell that story at the museum. And I don't think there's a conflict. I think there's always issues of overlap, you know, but the civilian space program, which is the program that Peggy and I have come out of, I think is critically important for this country. The research that's done, the fact that it is done in the public sphere, I think is critically important.

Dr. WHITSON. And I just—I would like to add on that I think that developing the infrastructure in space is—pulls a lot of the economic growth, with commercial providers coming in, with people like the SpaceXs, and the Boeings, and Orbital Northrop building new vehicles that are—actually have a targeted place to go. And I think our expansion into space will continually build that infrastructure that will allow us to continue. So—and none of that is going to hurt any military aspects that I know of, but I just think all of that development, all of that expansion, should be continued.

Ms. WEXTON. Very good. Thank you. I have no further questions, so I'll yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Posey.

Mr. POSEY. Thank you, Madam Chair. I'm curious, if you would explore a little bit more, Mr. Rose, the threat you see by the Chinese.

Mr. ROSE. Sir, one of the things that I would recommend is the Director of National Intelligence's Annual Threat Assessment—the bottom line is this. China is developing a full spectrum of anti-satellite capabilities designed to negate America's advantage in outer space, end stop.

Mr. POSEY. Yes, we get that. I remember in the 2012 Presidential debates Newt Gingrich said we need to establish a presence on the moon. He didn't say the Russians are doing it, the Chinese are committing to do it, he just said we need to do it, without going further, whereupon Santorum jumped up and said, you're just pandering to the I-4 Corridor. Romney said, well, that's the stupidest thing I ever heard. I'd fire anybody on my staff that suggested that. Of course, Mike Griffin, former NASA Administrative Supervisor, thought it was imminently important we go back.

Finally it got to Ron Paul, and Ron Paul said, much to his credit, it's important to our national defense. Then he joked, we need to send all politicians to the moon, and ended the discussion about space in the Presidential primary. Very next day, what happened? Dr. Stofan knows, and I'm sure Dr. Whitson knows what happened the very next day. They had to move the ISS. Why'd they have to move it? Space debris. Where'd it come from?

Mr. ROSE. China.

Mr. POSEY. Chinese satellite, 8,000 pounds. They took target practice on it. A week later they had to move the ISS again. Why'd

they have to move it this time? More space debris. Chinese again? No, Russian space debris. Well, why would the Chinese and Russians shoot their own dog? Just to prove to themselves, and the rest of the world, that they were capable of doing that. If they can take their own satellites out, they can take our satellites out.

So the, you know, the question that begged for an answer is, you know, what are we doing about it, and how can we make sure that it gets addressed? I think it's an important matter to national security.

Mr. ROSE. Sir, I think we need a comprehensive response. It needs to include norms of behavior so we prevent activities like China's ASAT test. It needs to include resilient U.S. systems that can operate in outer space. And it—we need to be able to respond if there is an attack on U.S. space assets.

Mr. POSEY. Yes.

Mr. ROSE. But at the same time, sir, I would just add, we also need to find a way to cooperate on common interests with both Russia and China.

Mr. POSEY. Yes. Any of the three of you read that book, "One Second After," William Forstchen's New York Times bestseller?

Mr. ROSE. No.

Mr. POSEY. I highly recommend it. It's riveting, it's very informative. It's based upon a confidential intelligence report that Members of Congress get, and it's staggering what happens. I mean, you know, we've got 30-some satellites that make our credit card use possible, our cell phones, our laptops, give us our weather reports. You know, you take a half dozen of those things out of operation, and we're in the Stone Age, and the consequences are lethal. They're not unfortunate, they're not uncomfortable, they're lethal for masses of people. So I think it's very, very important that we address this, and I thank the Chair for bringing this up today, and hope that we'll continue this discussion further. Thank you. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Perlmutter.

Mr. PERLMUTTER. Thank you, Madam Chair, and welcome to our panel. Good to see you all, and a couple of you have seen me hold up the bumper sticker before. And for those new Members to the Committee, we heard from NASA a couple years ago that 2033 was doable, if Congress provided consistent resources to the agency to get our astronauts to Mars. So, to the two doctors, can we do it? Is it possible for us to get our astronauts to Mars by 2033, if the resources are there from the Congress? Which is easier said than done, but that's my job, or our job.

Dr. STOFAN. Right. The scenarios that we looked at when I was at NASA—and I was wondering—I almost brought up your bumper sticker. I was wondering if you brought it along. So when we looked at the issue, you can easily get to Mars orbit by 2033. Getting to the Mars surface is harder. You would have to make a lot more investment in entry, descent, and landing technologies. But I think it's—it is certainly possible.

I hate to throw away that—around that word, possible, and impossible. 8-1/2 years from President Kennedy's call to get to the surface of the moon, and NASA did it starting from a place so far away from where we are right now. So I think we also have to keep

that in mind. When you challenge NASA to do great things, they have shown in the past they can do them, and I believe we can do it again.

Mr. PERLMUTTER. Dr. Whitson?

Dr. WHITSON. I absolutely agree, and I think political will is a huge factor in that. It's got to be the driver. It's the driver for China, and if we want it to be a driver, we can make it a driver, but it is largely political will, and some consistency in purpose, and, of course, a little cash helps.

Mr. PERLMUTTER. Thank you. Mr. Rose, you used an interesting term, and we really haven't heard it on the Science Committee until you did it. You talked about the civilian side and the military side being intertwined. That was your term. What do you mean by that? Because I agree with you, but I think you're the first one that's said something like that.

Mr. ROSE. Well, sir, for example, almost 80 percent of U.S. military communications travel over commercial satellites. So, you know, we in the community think they're our stovepipes, but they're really not, they're integrated. For example, debris. Debris does not discriminate from civilian versus military or national security payloads. It is—debris is a sustainability issue, but it's also a security issue. So my view, and I would say General Hyten's view, the Commander of U.S. Strategic Command, is that we have to think about space in a more integrated manner.

Now, I will commend the Space Subcommittee, because last year you held a hearing with the Strategic Forces Subcommittee on the future of SSA and space traffic management. I would encourage you to hold additional hearings jointly with the Committee, because, again, as we move forward, there's going to be—it's going to be increasingly difficult to separate national security space from civil and commercial space.

Mr. PERLMUTTER. Let me ask you a question about—I've got a couple other interests besides Mars, but Mars is the main thing, to get our astronauts there. But one of them involves sort of—the remote imaging——

Mr. ROSE. Um-hum.

Mr. PERLMUTTER [continuing]. And the ability to—of the commercial sector to start taking greater advantage of that. Do you have any comments about that?

Mr. ROSE. Sir, I don't want to go there, just because it quickly gets into classified information, but I'm thinking——

Mr. PERLMUTTER. Well—and that's the point——

Mr. ROSE. Yes.

Mr. PERLMUTTER [continuing]. Is we need to have a better system——

Mr. ROSE. Right.

Mr. PERLMUTTER [continuing]. That allows it to become commercial, and not always the intelligence agencies always saying, sorry, you can't show that stuff, even though it's my backyard in Arvada, Colorado, which is—probably don't want that——

Mr. ROSE. Yes.

Mr. PERLMUTTER [continuing]. Shown, but we need to be able to open that up more, and that's the point.

Mr. ROSE. Yes. And beginning a discussion with your colleagues on the Armed Services Committee, I think, would be a good place to start.

Mr. PERLMUTTER. OK. Last thing, and just more of a comment, but—is on space weather, which, again, where we have this integration, or this intertwine thing, because, as we have flares or radiation, it affects our astronauts, or Space Station, but it affects all of the national security satellites and things that we have. So I just appreciate your testimony. Thank you for your service to the country, and I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Olson.

Mr. OLSON. I thank the Chair, and it is an honor to have this panel before us this morning. I went to Rice University. As you mentioned, Dr. Stofan, John F. Kennedy made the great speech there on September 12 of 1962, committing this country to go to the moon before the decade ended, and we did that, as you said, in less than 8 years. Miraculous.

I moved right there at Kirby and NASA Road 1 in 1972. I was there for Apollo 17's homecoming, the last manned flight we've had since that time. I was there for the 1970s, and saw Skylab, a great success. Remember when she deployed we tore off the solar panel tore off the heat shield, so we had to make it habitable and get power there. We did that, and then we started flying the Space Shuttle, and built the Space Station. And as you guys had mentioned earlier, that Space Station's been occupied now for over 20 years straight by human beings.

I would like to just recognize Dr. Whitson for what she's done. I mean, she's a true hero to all Americans, especially young women. I could spend all my time gushing about your accomplishments, but I'll stick with the big one. This woman spent 665 days in orbit over multiple missions. That's a record for a human being in America, and for a woman in the entire world. So thank you for your inspiration. I'd like to ask you—one thing I'm concerned about is having a workforce for the future, which means people getting STEM educations. Dr. Whitson, how can you help us promote women getting that STEM education and being the next Dr. Whitson?

Dr. WHITSON. Well, I think they—being the next Dr. Stofan might be more impressive.

Mr. OLSON. She's——

Dr. WHITSON. But in any case, I definitely think NASA serves as an inspiration to a lot of our young people. It does require that we get out there and reach people at a very young age, I believe. I was nine when we first walked on the moon, and that's when I wanted to become an astronaut. And when I talk to young children, it is the age group that I think—around that timeframe that is most influenced by people telling them they can do some things, and achieve their goals. And so I think it's really important that we get to young people, and try to show them all the options that are out there, because, if they're exposed to these things, and see people doing these things where they might be in the future, it will inspire them.

Mr. OLSON. Yes, if they could see Bruce McCandless on a jetpack out there, in his own spacecraft, go out there and drive around the

Space Shuttle, that gets them inspired, because I saw that firsthand growing up on the Johnson Space Center. Dr. Stofan, like to add that comment, women in STEM? Any comments?

Dr. STOFAN. I think, you know, Marian Wright Edelman said if you can't see it, you can't be it, and so I think it's critically important that we get role models like Peggy out there as much—we try to tell all the stories in our museum. It's one of our goals for renovating the National Air and Space Museum, to make sure we tell all the stories. And I just think it's critically important that we show girls that they can be not just pilots and astronauts, but also someone who's building airplanes, someone who's repairing aircraft, someone who's building spacecraft. They can do anything.

Mr. OLSON. Let's just talk about the moon mission. In my humble opinion, I think that's the right mission for us. It was canceled by the Obama Administration constantly. I thought that was a mistake. But Mr. Trump has it coming back. I've heard from experts, if we're going to Mars, to train for that, we should probably train at the moon, in terms of gravity. You know, Mars has 1/3 of our gravity, the moon has 1/6. I know the pool there in Houston is great, but it's not actually training there. Also we talked about the Space Station debris. Hey, how about a Space Station on the moon? No debris issues. And so, Dr. Whitson, how do you think going to the moon helps us with here on Earth, a Space Station transition, and going to Mars and beyond?

Dr. WHITSON. Well, I think one of the most important aspects of our future research is actually trying to understand how we can utilize the resources either on the moon or on Mars in order to——

Mr. OLSON. Water.

Dr. WHITSON. Yes, water being a prime one, but there are lots of resources. For instance, if we can take the carbon dioxide out of the Martian atmosphere and make it into oxygen, these are the ways that we are going to be able to sustain our exploration—sustain our presence. And all of it is a building block to get to where we want to be, which is Mars, for at least 2020—or 33, and, you know, and beyond. So I really believe that.

Mr. OLSON. Well, thank you. I'll close by saying if you ever have a program, like taking Members of Congress into space, like Jake Hart and Bill Nelson, I'm number one in the line.

Chairwoman JOHNSON. Thank you——

Mr. OLSON. Thank you.

Chairwoman JOHNSON [continuing]. Very much. Dr. Bera.

Mr. BERA. Thank you, Madam Chairwoman. You know, in this conversation about getting more women into STEM, I think—I'm going to make note that the Chairperson of the Science, Space, and Technology Committee is a woman, that the Chairperson of the Space Subcommittee is a woman, and I think they're role models to inspire that next generation as well, as the father of a daughter. I want her to dream big.

There's so much that I want to talk about in 5 minutes. You know, ISS, what do we do next. I know we've talked a little bit about situational awareness, but we've touched on space debris, how do we clean up space. You know, commercial space, as more startup companies, et cetera, start to get into this area, and as more international institutions get into the space—who is the air

traffic controller? How do we navigate that? How do we do all that? I'd like the United States to write the rules of that road, that we can then take to the rest of the world. Obviously another one.

We talked about Mars 2033. As a child of the Apollo missions, you know, growing up in Downey, California, which is home of Rockwell International, and, you know, growing up with a lot of my friends whose parents worked in the aerospace industry, we challenged ourselves to do something we didn't know how to do, yet we did it faster, and we put the resources—it wasn't a Democratic or a Republican agenda. It wasn't an Executive Branch or a congressional agenda. And if, you know, I think it's possible for us to do Mars 2033. I think it's at least possible for us to challenge ourselves to do that, but it is going to take a long-term strategic vision. It can't change from one Administration to the next.

It is going to take a cohesive Congress, working with NASA, because you're looking at decade and multi-decadal challenges, and—for both NASA, as well as the commercial sector, and our partners out there, they can't make these investments if they're going to change every 4 years, and I think that's the challenge on us, that we ought to step up and actually put that strategic plan together.

A colleague touched on workforce issues as well. I do want to make sure NASA has that workforce. The impact of the government shutdown, my understanding is we lost some critical talent that we may never get back, and, again, I would put that on this body not to do that again, because it is hard enough for us to recruit the scientists that we need to fill these critical agencies. If we lose them, we're not getting them back. So let me ask a question, I guess.

Often in this body folks only see the allocations that we're making, the moneys that we're appropriating. Yes, we spent a lot of money on the Apollo mission, but we rarely quantify that return on investment, all the technologies that come about that. And I don't know if that's something that we've ever actually done, and maybe, Dr. Stofan, if we think about, you know, these aren't just cash outlays. These are investments that we're making, and there's huge return on those investments, and——

Dr. STOFAN. There's a number of different numbers out there. I know that NASA did one smaller-scale study looking at technology investments through the ISS, and what the return on, and you'll—if you Google this, which I have, you'll see numbers between sort of $3 and $5 in return for every dollar invested. I'm not sure there's ever been actually a rigorous study done, except for in small individual areas of NASA, but I think the benefit is clear. If NASA can publish a 1-inch thick volume every single year on spinoffs that came out of the Space Station, that's enough evidence for me.

Mr. BERA. I mean, it's pretty amazing. I had a chance to visit the NASA Ames facility in my home State of California, and visit a company called Made In Space that is doing 3D printing, and learning how we could 3D print the resources that we need, so if we go to the moon, you know, we're not going to have to ship all the materials up there, if they could take moon dust, turn that into the building blocks to build a habitable place on the moon. Same thing if we go to Mars. And the applications here at home are going to be tremendous as well. As a doctor, what we're learning

off of the Space Station with regards to health, as we try to better understand and address the growing impact of climate change and global warming, what we're going to learn from space, and through the space missions is going to be incredibly important to help us address some of our domestic challenges.

So, I do think, for this Committee, and for the Subcommittee, it probably does make sense for us to think about how we articulate the investment, but the real return on investment. How it is going to help us both economically, but also address some of the challenges. So, with that, I'll yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Baird.

Mr. BAIRD. Thank you, Madam Chair, and I appreciate all of our witnesses being here today. I just think this kind of discussion is extremely good as we try to make decisions about the budget and so on, but my first question goes to Dr. Whitson. I just want to compliment you for serving as the Commander of the International Space Station not once, but twice, that had to be an interesting experience. I'm not sure I'm ready to go with Dr. Olson yet, so I think I'll take a while to get in shape. But anyway, you make mention—I found this interesting. You make mention about the early stages of human habitation on the moon's surface, and—while we're taking advantage of local resources, and then someone mentioned water again, as you did in your testimony. So I guess my question is how applicable is it that we make a test run to the moon, maybe, and take advantage of some of the resources there as we try to go to Mars? Is that an essential component to our research?

Dr. WHITSON. I think it will be. We have found so many things in the 20 years of operating on ISS that, you know, we have brilliant engineers, but once we get it up there, and we test it out, we find out, well, maybe we ought to modify it to work better. And I think doing some of that exploratory testing on the lunar surface can help us be better prepared for what we will find when we get to Mars, because that's a lot, lot farther away. And so being better prepared is going to make the mission more likely to succeed.

But I think taking advantage of those resources that we can find on the moon potentially could even serve as a fuel depot if we—and send us out to Mars even easier. So that's an option for us, that we would build on the stepping stone of infrastructure to get us further and further out into space. So I really do feel that those steps are going to be important for us, and it's a good place for us to learn, where we're just a few days away from Earth, rather than, you know, 6, 8 months.

Mr. BAIRD. I share your concern there. That's anyway, my second question also goes to Dr. Whitson, and that's regarding, you know, the public's attention is drawn many times to NASA's activities in outer space, and yet we continue to work with critical forward-leaning technologies, such as low-boom supersonic demonstrators and hypersonic aircraft. So the question is, how can NASA best serve our Nation's needs for aviation research and development, and how should we focus in our limited resources when it comes to aeronautics?

Dr. WHITSON. Well, I think definitely NASA's still doing a lot of cutting-edge research in aeronautics, as well as space research, so I am very supportive of what we're doing to develop supersonic

space flight. I think it'll be a great spinoff, maybe even used by—commercially for other companies within the United States, hopefully building new aircraft that are going to take us further and faster, but also all of the software and other technologies developed to keep aircraft safe while in low—the really low Earth orbit.

Mr. BAIRD. Thank you. My next question, then, goes to Dr. Stofan, and that deals with, you know, we're starting a new Congress here, and we have an opportunity to take a critical look at NASA's near-term goals and their aspirations. So my first question is, what should NASA be focused on in the next year or two, and then what issues demand the agency's immediate attention? And I think some of that has been addressed already, but, just for my sake, would you elaborate on that?

Dr. STOFAN. Yes. I—to me the most critical thing, if you look at NASA over the next couple years, it's going to be maintaining the critical balance that NASA has across astrophysics, Earth science, planetary science, and heliophysics. Maintaining that scientific balance, making sure the investments are being made to gather data from—space weather came up earlier, to making sure that we're gathering data that helps farmers around the country, helps us understand our water resources around this country. Those data are critical, and we need to pay attention to the—those critical data sets.

And, as we move forward, saying, what is a sustainable, affordable plan for getting humans into deep space is critical. And then I'm very in favor, and happy, you brought up the supersonic—the hypersonic work that NASA does. Those investments really help move our aviation forward in this country, so——

Mr. BAIRD. Thank you. And——

Chairwoman JOHNSON. Thank you very much. Dr. Foster.

Mr. FOSTER. And thank you, Madam Chair, and thank you to our panel. You know, one of the things that strikes me is the difficulty in penciling out a, you know, sustainable, affordable plan for a really aggressive move into space is that in the last 50 years we've made very little progress in the cost per kilogram of getting stuff into low Earth orbit. You know, there's—if you look at all of the future plans, there's very little that could not be completely understood by Wernher von Braun, that we're up against fundamental physics limits in the specific impulse of chemical rockets.

And you mentioned the hypersonic work. You know, there are various ways—reusability. You know, the Shuttle was supposed to use—to reduce the cost per kilogram into orbit. It did not work. The cost of refurbishing space hardware to space specifications, you know, is large. And we're—even the proponents of reusing the booster stage, you know, claim less than a factor of two cost reduction.

And so my question is, when you make long term plans, how do you split your investment between just sort of using equipment that we know how to build, and have known how to build for 50 years, optimizing it somewhat, and investments in fundamental transformative research, you know, things like electromagnetic launch mechanisms, things like air breathing systems that get most of the energy for low Earth orbit, where you're at least getting the oxidizer from the atmosphere. And how do you, you know,

how do you split your investments, and are we making a mistake by just, you know, doing the same thing over, and over, and over, in terms of getting stuff into orbit? We're now returning to heavy launch vehicles as the cheap way to get stuff into orbit, which was the conclusion back in the 1960s.

And so it seems to me that we're underinvesting in the long-term research, particularly in getting past the barrier to getting into low Earth orbit. Anyone who wants to comment on that?

Dr. STOFAN. Yes. This is actually a pet issue of mine, and it was certainly something I tried to work on at NASA. There's always—when you're investing in future technologies, there's always a really difficult trade into do I put my money toward a flagship that maybe needs money to get off the ground 5 years from now, or am I investing in truly transformative technologies that are going to help us 20, 30 years down the line to do the really bold things that we would like to do? Whenever I go out and talk to elementary schools, or junior highs, or even high schools, I tell them that they have to go home that night and invent warp drive because of the very issues you just outlined.

One of my favorite programs at NASA is called NIAC. It's the NASA Innovative Advanced Concepts, where they do take a small—relatively small amount of money every year and invest in really far out ideas. I think those technology investments are really critical, and I would urge you, as you look at NASA's budget, to say, OK, clearly you have to really focus on near-term technologies, or we won't get the job in front of us done. But taking some portion of the money and investing in truly transformative technologies, I think, is critically important.

Mr. FOSTER. And the nation that comes up with those transformative technologies is going to own space, so it's my opinion that we've been underinvesting in this. You see it in national defense too. There were problems in the original Star Wars plan, which contemplated thousands of launches to support Star Wars, would've wrecked the upper atmosphere, OK? And this is another fundamental problem with, you know, with chemical rockets. And I really think it's another reason why we have to get past just doing the same thing again and again. Any other comments on that?

Dr. WHITSON. Well, I would just add on, I do think that we need to invest in newer technologies and research, and I think even on the International Space Station they're planning to put on a new ion propulsion to test.

Mr. FOSTER. Which doesn't get you into low Earth orbit. You know, ion propulsion drives——

Dr. WHITSON. Yes.

Mr. FOSTER [continuing]. Have fantastic——

Dr. WHITSON. That's true.

Mr. FOSTER [continuing]. Specific impulse, but they're useless for getting into low Earth orbit. And related to that, actually, is space nuclear power. There was a recent conference that I got a chance to address it, NETS it's called, Nuclear Engineering and Technology in Space, that was up at PNNL (Pacific Northwest National Laboratory) a few weeks ago, and one of the subjects there was the use of space nuclear reactors. There are two main uses. One of them is for propulsion, the other one is for power. When you actu-

ally go to the moon, go to Mars, it would be nice to have a compact nuclear reactor.

And one of the difficulties there is if all of the nations which will be spacefaring, which might be a dozen in our lifetimes, if they all start using high-enriched uranium, then we will have many, many nuclear weapons' worth of weapons-grade material used in those. And I was wondering what you think about the usefulness of having the U.S. lead the world in developing space-qualified reactor designs using low enriched, non-weapons-grade uranium, and really making that the standard for all spacefaring nations? Yes. Mr. Rose?

Mr. ROSE. Sir, I don't think I'm competent to talk about that, but I can take it for the record, if you'd like.

Mr. FOSTER. Yes. No, I think it's a very important issue, which we have to face, you know, in the next few years, as we define our space reactor R&D program. And I guess my time is up, and—yield back.

Chairwoman JOHNSON. Thank you very much. Dr. Babin.

Mr. BABIN. Yes, ma'am. Thank you, Madam Chair. I want to thank all of our illustrious witnesses for being here today, and quite a record amongst the two ladies sitting out there. And, as a father of three daughters and seven granddaughters, that's very inspiring, so thank you for what you all have done.

On April 11, 2018, this Committee held a hearing titled, "Scholars or Spies? Foreign Plots Targeting America's Research and Development." On September 27, 2016, this Committee held a hearing titled, "Are We Losing the Space Race to China?" On 20—June 20, 2014, this Committee held a hearing titled, "NASA Security: Assessing the Agency's Efforts to Protect Sensitive Information." According to the U.S.-China Economic and Security Review Commission annual report, China continues to pursue a broad counterspace program to challenge the U.S. information superiority in a conflict, and disrupt or destroy U.S. satellites, if necessary. Based on the number and diversity of China's existing developmental counter-space capabilities, China probably will be able to hold at risk U.S. national security satellites at every orbital regime over the next 5 to 10 years.

China also undertakes significant effort to acquire and assimilate foreign technologies, especially from the United States. And in 2007, China conducted an anti-satellite test, which has already been mentioned today, that produced the largest amount of orbital debris in a single event. NASA's Orbital Debris Program Office estimated that roughly 30 percent of the objects greater than 10 centimeters would still be in orbit by 2035. In 2011 this debris passed within 6 kilometers of the ISS.

Because of the risk posed by cooperation on space issues with China, Section 530 of the Fiscal Year 2019 Appropriations Act, as well as every Appropriations Act since 2011, prohibits NASA and the Office of Science and Technology Policy bilateral interaction with China unless the Administration can certify that China does not pose a threat to U.S. technology, and that they are no longer a violator of human rights.

So, Mr. Rose, should the Appropriations Committee revisit this prohibition, and if so, how can we ensure the protection of our na-

tional security, and prevent the theft of our Nation's intellectual property?

Mr. ROSE. Sir, I think you're absolutely correct, that China is developing a full range of anti-satellite capabilities, and I've been very outspoken on this, both——

Mr. BABIN. Yes, sir.

Mr. ROSE [continuing]. In——

Mr. BABIN. Appreciate it.

Mr. ROSE [continuing]. And outside of government. I did not recommend in my testimony that the Congress repeal. I—what I did recommend is that we need to manage China. We need a comprehensive strategy, and as part of that comprehensive strategy, the Committee should look at this. And this was driven, my testimony, by some comments that Charlie Bolden, the former administrator, made a couple of months ago. But I do not discount the potential thread that China poses to our space assets, however, we need to work with China on some of the sustainability issues. So——

Mr. BABIN. All right.

Mr. ROSE [continuing]. You know, we've got to get a balance.

Mr. BABIN. Absolutely. Thank you very much. I'd like to add an op-ed here into the record, Madam Chair, if you don't mind? "Navy Industry Partners are 'Under Cyber Siege' by Chinese Hackers, Review Asserts," if you don't mind.

Chairwoman JOHNSON. No objection.

Mr. BABIN. All right. Thank you. Now, I'd also like to ask all of you, if you don't mind, the International Space Station is one of our Nation's greatest technological and international achievements, and currently the U.S. and its partners are planning to operate the ISS through 2024. According to the National Research Council's Pathways Report from 2014, if NASA maintains a presence on the ISS past 2024, without significant increases to NASA's overall budget, it will lack the resources to fund the development of systems that will push human presence beyond low Earth orbit until late in the next decade.

This would leave the Orion vehicle without a clearly defined mission, yet abandoning ISS could mean ceding global leadership in low Earth orbit to other nations. How do we resolve this dilemma? If additional funding is the answer, where do you propose that we get the additional funding? And, Dr. Whitson, I'd like to ask that question of you first, and then, maybe, if we've got time, Dr. Stofan.

Dr. WHITSON. Sure. I think it's a very complex question. We've had to deal with it in the past in—for instance, we shut down the Shuttle program with no capability to launch U.S. citizens into orbit, and we are still waiting, 8 years later, for that capability. So I think we have to be very careful about how we plan a transition so that we can do it in such a way that we still don't lose that leadership in low Earth orbit as we transition further beyond. So I do think it's an important question to ask.

I'm not sure where the money comes from, but I think if we can encourage commercial, and maybe even more international partnerships, maybe that could help us decrease the funding from the ISS——

Mr. BABIN. OK.

Dr. WHITSON [continuing]. And allow it to go——

Mr. BABIN. Can we indulge, Madam Chairman, Dr. Stofan?

Dr. STOFAN. I agree with Peggy. I mean, the problem is, obviously, it's been long recognized that you need that wedge of funding that goes to the ISS, and certainly a deep space gateway would be a destination for Orion. So I do think you have to balance that retirement. And, as Peggy said, I think commercial and international partnerships are critical to say, how do we maintain a presence—a human presence in low Earth orbit while NASA focuses its resources on the next destination?

Mr. BABIN. OK. Thank you very much, and I yield back.

Chairwoman JOHNSON. Thank you very much. Mrs. Fletcher.

Mrs. FLETCHER. Thank you, Madam Chairwoman, and Ranking Member Lucas, for holding this important hearing today, and thank you to the really excellent witnesses that we've heard from testifying here this morning on the future of America in Space. As a native Houstonian, I grew up proud to hear Neil Armstrong's voice throughout my childhood saying, "Houston, Tranquility Base here. The Eagle has landed." And, as a Representative from the Houston delegation, along with my colleagues here on the Committee, we all share that same pride as a leader in space, and as a real home for NASA.

From the early days of the Gemini and Apollo missions, through the Space Shuttle Program, and the International Space Station, the Johnson Space Center continues to play, as it has, a pivotal role in leading, managing, and operating America's major human space programs. Additionally, the Johnson Space Center is a positive force in the greater Houston region, and plays a vital economic role in our community. The dollars spent in procurements, grants to educational institutions and non-profits, and aerospace contractors enhances business development, and creates jobs in our region. And, as we've heard today, investment in technology returns benefits that many of us don't even realize as we use them, everything from baby formula to ski boots. So I appreciate the testimony that we've heard. We're committed to that.

But we are seeing a change—some changes in the industry, and, Dr. Stofan, I'd like to hear from you a little bit more. In your testimony you talked about finding the right balance with the private sector that would allow NASA to focus on big-picture exploration and cutting-edge science in aeronautics. NASA is the second largest Federal employer in the Houston area, with nearly 3,000 civil servants, and more than 7,000 Federal contractors. So what do you think is the best way to foster cooperation that benefits NASA and the private sector as we head into this commercialized area in the space industry?

Dr. STOFAN. I think it's really thinking about roles and responsibilities. So what is the private sector best suited to do, and I think we've seen that with commercial crew coming forward. We've certainly seen that amply demonstrated with commercial cargo, where you've had SpaceX and Orbital Northrop Grumman delivering cargo to the Space Station, and we're soon to see SpaceX and Boeing sending crew to the Space Station.

And then, as we move to the moon, I think the question becomes ever more complex. What should NASA be investing in, where's the private sector going to put their investment, and how does that balance out to, again, make sure that NASA can continue its important science programs, its important aeronautical research, and continue to move humans outward? And so I think it is all about balance, and it's about looking at what is the private sector willing to take on? And I think we're going to see this, especially in the next decade, in terms of low Earth orbit. We've made a lot of investment on research on the Space Station. Is there an economic case, for example, for manufacturing, for drug development in low Earth orbit, where private companies will be willing to put the majority of their dollars because they see a profit motive. And that, I think, is going to play out over the next decade, and I think it's not clear what's going to happen.

Mrs. FLETCHER. Thank you. Would anyone else like to weigh in on that question?

Dr. WHITSON. I'd just like to add, I do think the International Space Station, on my last mission there, we were conducting a lot more complex, and—what I would call cutting-edge research. And I think there's going to be, you know, we were growing stem cells of various types, and doing research on new drugs and applications. And I do think that there can be a commercial presence, or a commercial outcome, that will be beneficial to pharmaceutical companies, or others like that, in the future. And so I—but I think it's going to take some advertising, I guess, to make that a reality.

Mrs. FLETCHER. Thank you. And, Mr. Rose, maybe I can take part of that question and kind of apply it to something that we've talked about, and you've been asked about a lot already this morning, which is the discussion about the debris that we're seeing. Do you think that there is potentially a role for some of the private sector to deal with cleaning up space debris, and preventing potential hazards and collisions from occurring?

Mr. ROSE. Absolutely, ma'am, but I think we need to do it in a way to ensure it's consistent with our national security. But the bottom line, you already have a number of companies and private entities that are looking at debris removal capability. So the bottom line is yes.

Mrs. FLETCHER. Thank you. I yield back my time.

Chairwoman JOHNSON. Thank you very much. Mr. Biggs.

Mr. BIGGS. Thank you, Madam Chair, and I thank each of you for being here with us today. Last year I participated in a panel on space in Arizona. It was—two major missions were a major focus of the conversation, and one of those missions is Osiris-REx. It's being led by the University of Arizona, and has already made contact with the asteroid Bennu. Another mission, called Psyche, which will head out to an all-metal asteroid of the same name, is scheduled to launch in 2022. That mission is being led by Arizona State University (ASU), notwithstanding our, you know, the recent developments on bribery, and getting into universities, and they didn't want to go to ASU. That's a shame, if they were interested in space, or partying, apparently.

But you will see that there's a common thread to both of these missions. They're both university-led missions. Osiris-REx came in

on time and on budget, and so far it looks like Psyche's on time, and will probably be on budget as well. So my question to you, our esteemed panel, great knowledge and experience on this panel, and I am delighted to be able to ask you this question, is—given that university-competable missions have an impressive record, do you think we, as policymakers, should encourage more of these joint efforts like this? And, if so, what do you see is the best way to facilitate that, both from the policymaker point of view, and also from the agency point of view?

Dr. STOFAN. Principal investigator (PI)-led missions—and I'm a big fan of both of the missions you mentioned, Psyche and Osiris-REx, incredible missions that are really going to help us understand the fundamental building blocks that made our own planet. These PI-led missions at NASA, whether it's in planetary science, astrophysics, heliophysics, or Earth science, where we do have a competed line—NASA does have competed lines, you are right, those missions have a wonderful track record of coming in on time and on budget.

And part of the reason is those missions have to go through a pretty rigorous proposal process. And so, when I spoke earlier about that upfront costing of a mission, and the effort that has to go in, that's a big reason why those missions tend to be—stay on budget. They go through a rigorous competition process, and they really have to hone their estimates. And they don't tend to try to do things that are really pushing technology, really pushing what we can do.

Face it, when you look at the design of James Webb, it is pushing every technology, from the sun shade to the mirrors themselves, and so you're going to get into trouble because there are so many unknown unknowns. With PI-led missions, that's been driven down to a much smaller box.

Mr. BIGGS. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Casten.

Mr. CASTEN. Thank you, Madam Chair. Thank you to the panel. I want to focus a little bit more on the Earth. In 2009. the National Academies published a study, "America's Future in Space," which listed, among other things, that NASA and NOAA should lead the formation of an international satellite observing architecture capable of monitoring global climate change and its consequences. I am troubled, angry, a little bit frightened by the fact that the Trump budgets have consistently scaled back on those programs in their budget proposals, including the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, and the Climate Absolute Radiance and Refractivity Observatory (CLARREO) pathfinder mission, both of which were designed to really study how our climate is changing, and what we need to know to try to stay ahead of this, rather than falling behind.

First question is for Dr. Stofan. Are we doing enough currently to meet the recommendations made by the National Academies in 2009, and if not, what kinds of investments should we be prioritizing to make sure we're on top of climate science in space?

Dr. STOFAN. PACE and CLARREO were both recommendations of the previous Decadal Survey, as you said, and there has actually subsequently been a Decadal that came out a year ago that had

subsequent recommendations, but certainly I think it's critically important for NASA to implement the Decadal, because you've got scientists that come from around the country, really put aside their own specific research and say, how do we really pick the best missions to move the science forward? That's where PACE and CLARREO came from. Those missions are critical to help us understand this planet, and the recommendations of the subsequent Decadal, when we now know so much more about climate change, and so much more about how the effects of climate change are affecting us right now, from increased severe weather, to impacts on agriculture. Too much water in some places, too little in other places. So the missions that the scientific community recommends are really critical not just to helping us understand and model climate change, but to help us mitigate the effects that we are already seeing, not just in this country, but around the world.

Mr. CASTEN. Thank you. You'd mentioned mitigation, and watching, I want to focus somewhat more narrowly now on the actual emissions release, and—for non-CO_2 greenhouse gases. In 2014, a European Space Agency (ESA) satellite found, between 2003 and 2009, a methane hot spot in the four corners region. It was tied to natural gas production, and the numbers that I was just blown away by was that, after they had actually crunched the data, it turned out that the EPA (Environmental Protection Agency) estimates of fugitive emissions were off by 50, 75, 80 percent. Without ESA's satellite, we never would have even spotted the leak, much less have had a sense of that.

In 2015, there was a gas leak at a facility in Aliso Canyon Oil Field in Southern California that released 100,000 tons of methane. And methane, as you know, but it's, you know, it's about 80 times as potent a greenhouse gas over 10 years as CO_2. The satellite technologies deployed together within the private sector, and those proposed for use in the Environmental Defense Fund's methane sat could easily detect those kind of leaks.

My question for you all is, do we currently have a satellite network that's necessary to detect that, or are we going to rely on other governments or the private sector to keep an eye on that?

Dr. STOFAN. Right now that is the situation, and that—I believe methane was—monitoring methane was something that came out of the most recent Decadal. So the fact the private sector is coming forward with a satellite—methane is very hard to measure from space. Getting the right resolution, making sure that you're accurately measuring it is tough, so it's been an area that's needed technology development that's been going on. But, as you say, the Europeans had come forward with a satellite. The U.S. has been studying methane monitoring. And, as you say, it's all about intelligence. If you can measure things on the ground, you can then make the decisions that you need to make. If we don't know what's happening, especially with methane, which is such a potent greenhouse gas, as you say, you know, you're working in the blind. So these satellite data are incredibly important not just for the scientific community, but for decisionmakers who have to decide how to best manage the environment locally, regionally, and in this country.

Mr. CASTEN. And question for all the panelists, would it be fair to conclude that relying on that data from the private sector and other governments, both in the climate space and for other purposes, frankly, is a risk to our national security, to our wellbeing, and ultimately to our competitiveness?

Dr. WHITSON. Well, certainly to the competitiveness, I think. We need to be able to—we need to lead, if we're going to lead. We have to be there.

Mr. ROSE. I don't have anything to add, sir.

Mr. CASTEN. Thank you. I yield back my time.

Chairwoman JOHNSON. Thank you very much. Mr. Waltz.

Mr. WALTZ. Thank you, Madam Chairman. Just to echo some of the other sentiments of my colleagues, I was just on the floor of the House in commemoration of National Women's History Month, and also, as a son of a single mother, and father of a 15-year-old girl, I truly applaud the groundbreaking, ceiling-breaking work that both of you have done.

This Committee, I think, really has—and all of us really have, I think, a mission and a mandate to continue to explain to all Americans, and to educate all Americans, how dependent our modern way of life is on space, from over-the-horizon navigation, to our banking system, to how we communicate, all things that we've talked about today. But I don't think that is fully realized by everyone, and I commend your work to continue to do that, and I certainly take that on as one of my missions. But then also, at the same time, as we've talked about, how fragile that infrastructure is. It's not built for redundancy, it's not built for survivability, and it truly, I think, is a national vulnerability at this point.

I do want to take a moment, though, to applaud this Administration for breathing new life into the Space Council, the space policy directives, my colleagues, and their op-eds. Along those lines, I do think it's worth noting that NASA is the only civilian agency in the President's budget that just came over that is not looking at a potential cut. And, of course, we're so excited about the private sector. I represent Northeast Florida, and space is in our DNA, and I think that triangle between Cape Canaveral, Daytona, and Embry-Riddle, which is an aeronautical university which is in my district in Orlando, truly can be at the heart of the future space industry. So, to questions.

I wanted to give you, Mr. Rose, a chance to also weigh in on this perception, perhaps reality, that there's this kind of zero sum, from a budgetary standpoint, in sustaining the Space Station, and having the resources to truly make the moon and deep space a reality. Is that a viable path to expand the partnerships, and to truly make that available for commercial use in the timeframe that we need, in your opinion?

Mr. ROSE. Sir, to be honest with you, I don't know. As I mentioned——

Mr. WALTZ. OK.

Mr. ROSE [continuing]. Earlier, I'm kind of a military space guy, so I don't——

Mr. WALTZ. OK.

Mr. ROSE [continuing]. Know the answer, sorry.

Mr. WALTZ. That's OK. But I was just out at the National Reconnaissance Office and, for me, what was so telling there was how interdependent all of these things are. I mean, just the things that they're able to do now because of what the private sector is doing, and the affordability of launch, all of those things, is really fantastic.

Then maybe I'll open it up to a broader question. How can NASA do things better? I mean, it's one thing to say we need more, you know, more is always better in terms of resources, I got it, but there is an efficiency component here, and there's a perception, at least coming to me, someone who's new to the Committee, that NASA sees each of its programs as somewhat siloed, or maybe they are siloed, as competing for limited resources. So how do we change that sentiment, if you agree that it exists, to cultivate a more streamlined agency, and how can we help?

Dr. WHITSON. Well, I think one of the best ways we can do that is to expand on what we've done with commercial cargo and commercial crew, to try and take advantage of the innovative ideas out there, and have them developed in part by private agencies, giving them a platform and a place to go. In essence we pay for it, but much less than what it would cost us if we had done it ourselves. So I think we need to expand on those capabilities throughout—wherever we can, whether it's other technologies that we can develop on the moon for——

Mr. WALTZ. Do you sense that—or is government being a hindrance or help? And——

Dr. WHITSON. I think——

Mr. WALTZ [continuing]. I mean, what can we do from, you know, from our foxhole here?

Dr. WHITSON. Overall I think the government provides the leadership—NASA provides the leadership that is required. And even our international partners that we work with say, well, when's NASA going to have the definitive plan, so that we can get on board? Because they expect us to be the leader, and we need to serve that role as a leader. I think NASA is that role.

Mr. WALTZ. So having, or better communicating, the—those long-range objectives——

Dr. WHITSON. Yes.

Mr. WALTZ [continuing]. Right, that the private sector can then——

Dr. WHITSON. Yes.

Mr. WALTZ [continuing]. You know, make sensible investments into. Is that a fair statement?

Dr. WHITSON. And to integrate it with the plans in such a way as to optimize the outcome, and get——

Mr. WALTZ. Should the private sector be part of the planning process, or is it, you know, we plan, and then we'll let you know what it is?

Dr. WHITSON. I don't think it would hurt to have the private sector as a part of the planning process.

Mr. WALTZ. OK. Thank you. I yield my time.

Chairwoman JOHNSON. Thank you very much. Just want to make a comment, there was a 2.3 decrease in the budget. Thank you. It really doesn't keep up with inflation. Ms. Stevens.

Ms. STEVENS. Thank you so much, and thank you to our distinguished panelists for joining us for this exciting hearing on "America in Space: Future Visions, Current Issues". I represent a district in southeastern Michigan, the suburbs of Detroit, known for its auto industry, known for what we do here on planet Earth, but our robust supply chain is also deeply connected to aerospace. Some of NASA's prime contractors, Lockheed Martin and Northrop Grumman, are responsible for many contracts, many awards, and, in fact, we have up to 80 companies in Michigan alone that have helped to build NASA's space exploration systems to the moon, Mars, and beyond. So deeply appreciate the big visions that we have discussed today, particularly as tied to another asset that we here in Michigan appreciate, and that is the technical workforce, and the best-in-class workforce. And I know that workforce development and skills training has come up today, along with commercialization, which we'll continue to push on.

My first question is for you, Dr. Stofan. I read through your testimony, and appreciate everything that you packed in in what is the 5 minutes that you get to do your testimony. One line in particular jumped out to me, the discovery of extraterrestrial life, as you described, being a defining moment in the 21st century, just as the moon landing was. And, for those of you watching at home, I imagine, you know, we have visions of what extraterrestrial life is. Movies tend to define it, but I was wondering, from your scientific standpoint, could you kind of give us a description of what extraterrestrial life might be?

Dr. STOFAN. Yes. And I'm afraid for so many people listening at home they might be a little disappointed that I'm not talking about little green men, especially if we're looking at fossil evidence of life on Mars, if we're looking under the icy crust of Europa. We're probably talking about microbes, and I'd have to take you back to the fact that life here on Earth evolved in the oceans. It stayed in the oceans for over a billion years, and it really didn't get much past single cell, you know, pond scum, algae, for a really, really long time, so billions of years to get very complex life. So when we look outward in our solar system, we're really anticipating we're going to find sort of single cell, maybe very simple multi-celled organisms.

So you might say, well, then, why are we looking? That's so boring. It's not boring, because we have these fundamental questions. Do they—does it have cell structure that—like our life here on Earth does? Does it have RNA, does it have DNA, and how can we use that information to better understand life here on Earth?

Ms. STEVENS. And what would it mean for us—and I don't know if this was your testimony. I know it's come up today. But what would it mean for us to kind of look to put some sort of colony on Mars, or some long-term colonization on Mars?

Dr. STOFAN. You know, Mars is really hard, and Peggy can answer this better than I can, but, you know, Mars is hard. So when you think of those initial scientists, engineers, doctors going to Mars, think a little bit more like an Antarctic outpost. You know, Mars is tough. It's—there's a lot of radiation on the surface. It's a tough environment for humans, so it's going to start small, and grow over time.

Dr. WHITSON. And I think the—that it will be successful if we can take advantage of those resources we can use there. So—because the more we have to send things to orbit, the more expensive it gets. And if we can, you know, make our own oxygen out of the CO_2 in their atmosphere—and think about what—that might have impacts here on Earth too. But if we can remove the oxygen from the—or the CO_2 from the Martian atmosphere and make oxygen, you know, that'll be a huge savings for us. And just that development of making structures—three dimensionally making structures out of materials that are found there, that will make a plan like that feasible. Otherwise, it just—it's not going to be feasible. It would just take too many launches and too much money to get us there.

Ms. STEVENS. We frequently say on this Committee that the Science Committee is the best kept secret in Congress, and I think saying make your own oxygen is another example of how that can be the case. With just the last remaining seconds, Mr. Rose, I wanted to get you in here. We really appreciated your comments on bilateral—multinational relationships, and I think that gets important as, you know, even if it's microbes, as we talk about, you know, longstanding presence on Mars, what—could you speak to that?

Mr. ROSE. Ma'am, I would say international cooperation is key to everything we do in the future with regards to space, whether that's civil or national security.

Ms. STEVENS. Thank you. I'll yield back. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Cloud.

Mr. CLOUD. Thank you. I really appreciate you being here. I echo the comments, this is the fun committee to be on. This is Plan B for me. I initially wanted to be an astronaut, so I'm a little jealous. But, you know, for us the challenge is, you know, I want to kind of look at the national security competitive aspects to the situation, and I've been committee hopping, so I apologize if I'm repeating anything. But the challenge for us is it's our job to manage the checkbook, and so we're looking at national security issues. No doubt space is important from our commerce, from military assets, from having the high ground on information, how integrated it is with our phones, and, you know, just—GPS, and everything we do nowadays, but yet many defense experts are now looking at our national debt, they'll list that as the primary concern from a national security standpoint.

And so, you know, we all buy into how awesome flagship missions are, not debating whether they should be, but then, at the same time, we've seen this explosion in the commercial space industry of innovation, and being able to do things—and it's grown pretty quickly, in the sense of being able to be innovators, and do things efficiently. And even your comments, in the sense that seems to be where the innovation is, or a lot of it, at this point, is in the commercial space industry, and being able to do things efficiently and effectively. You know, I think back to the failure is not an option days. I would've thought NASA is the primary innovator. So how do we kind of bring that together? I can't help but wonder, is there a culture issue, in a sense, that, you know, we have James Webb on one hand, we have explosion of innovation on

the other hand. Is there something NASA can do to be innovative, to begin to do things more efficiently? Is that even a question, or do we kind of fall back on the flagship argument? Which is a valid one, not debating it, but——

Dr. STOFAN. You know, I think NASA is doing things innovatively, and I think when you look at the design of Webb, that's innovation in and of itself. And I would remind you, you know, we're trying to image within a few million years of the Big Bang. We are measuring the atmospheres of planets around other stars. We are doing amazing things, and that's what 60 years of leadership at NASA has done. It has made us the world leaders in astrophysics, in Earth science, in planetary science, in heliophysics. It puts us in an amazing position, and with each of those innovations comes leadership and technology, and those technologies spin off in ways that benefit our economy.

Dr. WHITSON. And I'd just like to add on, just to clarify my previous statement about—commercial providers are doing things very innovatively. They can do them faster than NASA. NASA is also doing things in an innovative way, but we have a different focus, a different mission, that we're looking further into the future for. And so I think that is the distinction between the two. NASA is an incredible problem solver. We're taking the really, really big problems and trying to bite them—make them into bite-size pieces. And I think if we can hand some of those pieces off to commercial to do a faster turnaround, then together I think we can be the problem solvers that will get us to the lunar——

Mr. CLOUD. I've talked to some people in the private space industry that, of course, most of those came from NASA, and, you know, the brain trust has been dispersed in a sense, and asked them specifically, like, what's the difference? And just the ability to move quicker, I think, was part of it. And I, you know, I don't know if there's stuff that we could do to make that simpler on you either, and I'd be open to those kind of ideas.

Mr. Rose, in a recent article advocating for the creation of U.S. Space Command, you acknowledged that both Russia and China are developing anti-satellite weapons to threaten the U.S. and our allies. Are we prepared to respond to an anti-satellite attack?

Mr. ROSE. Sir, we are getting better. And I want to stress that this is something that the Obama Administration was working on, and I give a lot of credit to the Trump Administration for highlighting public attention on this. We need to do a couple of things. One, we need to enhance our diplomatic efforts to develop norms of behavior, but second we need to enhance the resiliency of our space architectures. One of the reasons Russia and China are developing these capabilities is because they believe we have an asymmetric vulnerability.

So going to one of your first points, I think it's in critical—it's critical that we provide sufficient budgetary support for enhancing the resiliency of our national security space architectures.

Mr. CLOUD. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Norman.

Mr. NORMAN. Thank you, Madam Johnson—Madam Chair. Thank each one of you for taking your time to come here. We value your service.

Mr. Rose, I—you made a comment that we need more civil dialog, and I think norms of behavior. I'm from South Carolina. We have Shaw Air Force Base. I got a front row seat to China when I went in that small company in Chesterfield, South Carolina that had a center of the business walled off. I said, can I get in—can I go see it? No. Why not? Well, we had a particular person who had the magic patent that knew how to make this particular item. Lo and behold, a month later, he was gone. Lo and behold, when they did the research, he was hired by a China firm. They're now competing with—they paid him a lot of money. I had a front row seat when I went up in that F-16, and the pilot, when you mentioned China, his face, not only did it get red, it got—and he wouldn't say anything. He just said, we've got a problem.

And I guess what I would add is China is a dictatorship. They're not choir boys. They don't sell Girl Scout cookies on a daily basis. I guess I would ask, and this is kind of in line with Congressman Cloud, the only thing that I think they understand is leverage, and the only thing—you can have all the civil dialog that you want. I agree in being civil, but the bottom line, if they can make money, if they can steal your patents and your product, you see that as a problem?

Mr. ROSE. I certainly—sorry. I certainly see that as a problem, and my point is, sir, civil dialog alone is not going to solve the China problem. It needs to be part of a package that includes military capabilities. Very much with regards to the Soviets in the 1970s, you know? In the 1970s we had a very strong deterrence posture against the Soviets, but we also had opportunities for civil cooperation, the Apollo-Soyuz mission, for example.

So my bottom line is we have to go into this with our eyes wide open about China. I believe that we are in a great power competition, but dialog needs to be part of our response, not just military capabilities. Military capabilities, but they're not enough.

Mr. NORMAN. Which do they respond to more, dialog or military capability?

Mr. ROSE. I think we need to have solid military capabilities to ensure we have successful dialog.

Mr. NORMAN. OK. Thank you. One thing—in my State of South Carolina, NASA has had a tremendous impact. All three major research universities receive funding from NASA. NASA is often thought to be confined to the States of Texas and Florida, and it's obvious to me that NASA research should be done across the Nation. Can any of you expand on the benefits and why we need that?

Dr. STOFAN. You know, the strong NASA research takes place—in astrophysics, heliophysics, Earth science, and planetary science takes place in universities all across this country, and that's critical because the best brains are located all across the country. And that investment, also, is encouraging the next generation to get involved in science, technology, engineering, and mathematics careers. So I believe the creative research, the innovative research that's taking place out at universities around the country, that NASA sends the far bulk of its research dollars out the door into the academic system, out to industry, is critically important for the health of the agency, but for the health of the country.

Mr. NORMAN. Dr. Whitson?

Dr. WHITSON. I concur with Dr. Stofan. And, you know, we have 10 NASA centers throughout, you know, the United States, and the contractors that provide all our supplies for Space Station, you know, it's—almost every State has a contributor in some form or fashion. And so I think we are very distributed—NASA is very distributed throughout our Nation.

Mr. NORMAN. Thank you. Mr. Rose?

Mr. ROSE. Nothing to add.

Mr. NORMAN. Great. I yield back the balance of my time.

Chairwoman JOHNSON. Thank you very much. That concludes our last questioner. Let me express my great appreciation to our witnesses, Dr. Stofan, Dr. Whitson, and Mr. Rose. We appreciate you being here, and for all you've done.

And before we close the hearing, I want to announce that the record will remain open for 2 weeks for additional statements from the Members, or for any additional questions the Committee may ask the witnesses. Our witnesses are now excused, and the meeting is adjourned.

[Whereupon, at 12:14 p.m., the committee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Ellen Stofan

Stofan Responses "America in Space: Future Vision, Current Issues"

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"America in Space: Future Visions, Current Issues"

Questions for the Record to:
Dr. Ellen Stofan
Submitted by Chairwoman Johnson

1. In your prepared statement, you ask if we are on the right path to realize a bright future in space, and you answer "*a tentative yes, with opportunities and challenges.*" Could you expand on your comment?

The challenge and opportunity remains how do we control costs, maintain consistent and predictable funding, form meaningful public private and international partnerships, and take on appropriate risk to accomplish such an audacious goal. All of the stakeholders need to have a common understanding of these four elements in order to achieve our bright future in space.

2. As we think about visions for America's future in space science, the nature of dark energy and dark matter in the universe are phenomena we don't yet understand. In fact, the highest priority of the last National Academies astronomy and astrophysics decadal survey was the WFIRST mission, which would investigate dark energy and also carry out research on exoplanets. The Administration has zeroed-out funding for WFIRST in its FY 2020 budget request for NASA. What would terminating this mission mean for America's future and leadership in space science? What message would it send to the well-established, community-based, science prioritization process that has been used for decades, especially as the next astrophysics decadal survey gets underway?

The Decadal Surveys produced by the National Academies for Astronomy and Astrophysics, Biological and Physical Science, Earth Science and Applications, Planetary Science, and Solar and Space Physics, provide a scientific and technical consensus on where the most significant progress can be made in the different disciplines over the coming decade. It is a proven, trusted, consensus process in each case, involving hundreds of scientists and technologists from across the country, and including input on the best science done around the world. It is a peer-reviewed process that has helped to keep the U.S. in a leadership position across multiple scientific disciplines.

At the Museum we recently hosted the celebration of the first image of a black hole by the Event Horizon Telescope. This project is just one example of how a long-term, steady commitment to U.S. leadership and international cooperation in astronomy and astrophysics can keep us at the forefront of discovery, inspiring and engaging the public.

I am unable to answer the question about the WFIRST mission and refer the Committee to NASA or the Administration.

3. What worries you most about the future of U.S. leadership in space exploration and what should the Committee be doing to address those concerns?

U.S. leadership will continue if NASA continues to follow the recommendations of the National Academies Decadal Surveys, and by following the recommendations of the Academy "Pathways' report. The legacy of Apollo shows us what can be accomplished when we commit to a challenging national goal, and enlist the support of academia, the government and private industry. Apollo was not just the brave astronauts- it was over 400,000 Americans from across the country who made it happen. The generation of scientists, technologists and engineers inspired by Apollo changed this country, helping to power an economic engine. To progress in exploration we need a true commitment by focusing and investing in the technology and science necessary, and pursuing innovation and private and international partnerships.

NASA's leadership in Earth Science, Planetary Science, Heliophysics, Microgravity Sciences, and Astrophysics is critical. This balance of science spurs innovation, helps us understand our changing climate, and pushes technology forward. More than that, NASA's programs inspire kids around the country. These inspired kids are the inventors, innovators and entrepreneurs of tomorrow.

4. Society depends on space activities to support every-day functions and operations and indeed, space activities are part of our infrastructure. However, at a 2017 National Academies workshop on America's Future in Space, participants noted the lack of public awareness of the nation's space activities. What do can NASA to help change that awareness, and what can Congress do to increase awareness?

In the renovated Smithsonian National Air and Space Museum, we will have a new gallery called 'One World Connected' that will help educate the public about how space data touches their lives- from the technologies in their cellphones, to the GPS guidance that helped bring them to the museum, to the space data that helps farmers make better decisions about water and land use. Museums like Air and Space are a critical tool to help the public understand how space touches their lives in so many ways, and to help inspire the next generation to move us even further into the future.

NASA plays a critical role in educating the public about space. Its missions inspire millions of students and adults every year. When NASA does things that show the public where we are headed and why, such as Scott Kelly's One Year mission on the ISS, or searches for life on Mars, or finds Earth-like planets around other stars, the public becomes very engaged and inspired. People are also engaged and inspired by stories of heroic figures, with a prime example being the response to the movie 'Hidden Figures'. Congressional support of the Smithsonian and National Academy of Sciences' education programs help to engage students across the country with these stories.

The stories of the people of NASA, from Katherine Johnson to Peggy Whitson, are stories that people just like any of us can do amazing things and change the world. The American story is a

story of hope and progress, and nothing exemplifies that more than the stories of space exploration- it is why the National Air and Space Museum is the most visited museum in the U.S. and the third-most visited in the world. Education and public outreach programming to me is critical to these stories reaching the world, to inspire the next Katherine Johnson or Orville Wright.

5. How do we ensure that NASA's infrastructure and workforce will be aligned with the challenging goals the agency has been given? Is there a clear understanding of how to prioritize the skills and infrastructure needed to enable our future goals?

As I have left the agency over two years ago, I would defer this question to NASA.

6. In his prepared statement, Mr. Rose recommended that "*the committee review the impact of the current legislative language*." He also stated that "*China is a major space power and we should find ways to cooperate where practicable*". What are your perspectives on his recommendations?

I am a major proponent of international cooperation, as I wrote my Ph.D. thesis using Soviet data of Venus and working with Soviet scientists, and I have worked on international missions most of my career. International cooperation provides a means of leveraging the best minds in the world, maximizing science by spreading the cost of exploration around many nations, and provides a way to continue to work with others when other paths are more difficult. The International Space Station is a prime example of how nations can work together productively and cooperatively.

Questions for the Record to:
Dr. Ellen Stofan
Submitted by Congresswoman Haley Stevens

Rare Earth Elements (REE) are used for many commercial applications including electronic devices, automobiles, batteries, and national security applications such as missile-defense systems. Today, we are faced with the reality that China accounts for more than 90% of global production of Rare Earth Elements, and the stakes are high for the United States.

A report by the Congressional Research Service suggested that the United States increase investment in greater global exploration for Rare Earth Elements and establish our own national "stockpile" of specific REE broadly needed for "green initiatives" and defense applications.

Leading theories and our own scientific explorations suggest that the Moon is composed of roughly the same chemical building blocks as Earth, which means that it is likely a good source of these Rare Earth Elements. The private sector has already shown a great interest in lunar mining for these valuable elements and is investing in REE research and development in space.

Where do you think the federal government can play a role in commercial space travel to the Moon and lunar mining that could help the U.S. in our national security goals as it relates to the discovery and stockpiling of Rare Earth Elements?

While REE's and water are present on the Moon, the cost of extracting them (infrastructure required, transport of infrastructure and mined materials, cost to maintain infrastructure) is not well understood. The cost to mine REE's or water on the Moon should be carefully investigated, to ensure that the scope of the investment required is understood.

Questions for the Record to:
Dr. Ellen Stofan
Submitted by Congressman Troy Balderson

One of my legislative priorities is workforce development. You all have exceptionally unique backgrounds that led you to extraordinary careers. How could Congress do a better job to help close skill gaps that you have seen firsthand in the sciences and space exploration fields?

Workforce development is a critical issue for the National Air and Space Museum, where we seek to inspire the next generation of innovators and explorers. The aviation and aerospace industry needs the next generation workforce- careers all the way from designers, to manufacturing and repair, to users. This means welders and pilots, engineers and coders, just to name a few. But we need to engage all kids- our workforce needs to look like our population or we are leaving talent on the table. So at museums like mine, we need to tell ALL the stories- from Orville Wright to Katherine Johnson to Margaret Hamilton to Charlie Bolden. We need to engage kids in how STEM subjects are actually used- from NASA spacecraft to flying cars. We need to emphasize stories of innovation, entrepreneurship, and teamwork. It goes all the way from qualified STEM teachers, which we help at the Smithsonian through a number of programs, to programs like INCLUDES at NSF. The recent report 'Charting a Course for Success: America's Strategy for STEM Education' from CoSTEM outlines many successful programs, and supports the idea of STEM ecosystems: how can we foster partnerships so that all of these programs can work better together to create an effective pipeline. Finally, we need to ensure that universities and workplaces offer inclusive environments, so that all who can contribute are welcomed and treated equitably.

Responses by Dr. Peggy Whitson

"America in Space: Future Visions, Current Issues"

Questions for the Record to:
Dr. Peggy Whitson
Submitted by Chairwoman Johnson

1. Society depends on space activities to support every-day functions and operations and indeed, space activities are part of our infrastructure. However, at a 2017 National Academies workshop on America's Future in Space, participants noted the lack of public awareness of the nation's space activities. What do can NASA to help change that awareness, and what can Congress do to increase awareness?

I am not sure of the current status of NASA's educational outreach program. With funding priorities, this area has been diminished in the past. It's difficult to make an impact if there are no means with which to try.

2 How do we ensure that NASA's infrasfructure and workforce will be aligned with the challenging goals the agency has been given? Is there a clear understanding of how to prioritize the skills and infrastructure needed to enable our future goals?

NASA's experience base is unrivaled, however, future success will require the incorporation of new and innovative ideas and processes to integrate seamlessly with commercial partners who might enable quicker response in some areas.

3. What worries you most about the future of U.S. leadership in space exploration and what should the Committee be doing to address those concerns?

I am worried most about the constancy of planning and political will to ensure that we will be successful in our goals of space exploration. Because of the complexity of design and implementation of a space program, there needs to be consistent support between administrations, with minimal perturbations that would preclude a successful outcome.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
"America in Space: Future Visions, Current Issues"

Questions for the Record to:
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HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

Where do you think the federal government can play a role in commercial space travel to the Moon and lunar mining that could help the U.S. in our national security goals as it relates to the discovery and stockpiling of Rare Earth Elements?

Allowing new and innovative approaches for NASA collaboration with commercial partners could be an avenue that would address mining of Rare Earth Elements. Many current contracting and policy limitations hamstring NASA's ability to collaborate with commercial partners. Development of new, more flexible, faster processes would lighten the bureaucratic load and potentially enhance the commercial partnerships.

"America in Space: Future Visions, Current Issues"

Questions for the Record to:
Dr. Peggy Whitson

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
Submitted by Congressman Troy Balderson

1. What can we do better for astronauts when they return from space, particularly after prolonged periods of time in space conditions?

   Long term astronaut health care would enable the continuation of data collection and assessment that will be required for our better understanding of the long term health effects of space flight on humans.

2. One of my legislative priorities is workforce development. You all have exceptionally unique backgrounds that led you to exfraordinary careers. How could Congress do a better job to help close skill gaps that you have seen firsthand in the sciences and space exploration fields?

   Our world and technology are changing at a rapid pace. And unfortunately, our educational systems are generally not keeping up with even a fraction of those changes. Support of educational funding for advanced science development would be a huge step in the right direction for addressing these inadequacies.

Responses by Mr. Frank Rose

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"America in Space: Future Visions, Current Issues"

Questions for the Record to:
Mr. Frank Rose
Submitted by Chairwoman Johnson

1. China's presence in space continues to grow. Current law, however, prohibits NASA from working bilaterally with Chinese state entities. In your prepared statement, you "*recommend that the committee review the impact of the current legislative language.*" You also state that "*China is a major space power and we should find ways to cooperate where practicable*". Why would it be important to engage with China on limited areas of bilateral cooperation? What are the potential benefits and risks of allowing cooperation with China?

2. How are other nations approaching infrastructure and workforce development to build their growing space capabilities?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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Questions for the Record to:
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HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"America in Space: Future Visions, Current Issues"

Questions for the Record to:
Mr. Frank Rose
Submitted by Congressman Bill Foster

NASA has primarily powered its deep space probes with radioisotope thermoelectric generators (RTGs) using Pu-238. It has recently been increasing efforts to develop fission reactors, which can provide both propulsion and power. NASA is currently developing nuclear thermal propulsion systems using low-enriched uranium (LEU), and nuclear reactor power systems using highly-enriched uranium (HEU). If all the spacefaring nations start using HEU reactors, then it would involve the utilization of a significant amount of weapons-grade material. Could the U.S. lead the way in developing space-qualified reactor power system designs using LEU? If the U.S. develops such a design, is it reasonable to believe it would be adopted as a de facto standard by other spacefaring nations?

Chairwoman Johnson

Cooperation with China

- From my perspective, there are several reasons what we should seek cooperation with China. First, cooperation would provide the United States with some insight into China's space program. Second, as I outlined in my written statement, the long-term sustainability and safety of the outer space environment is increasingly at risk due to the growth in orbital debris and the rise of mega-satellite constellations. Active engagement with China on these issues is critical to effectively addressing these challenges. Finally, cooperation with China could help build a level of trust between our two nations, which is currently lacking. As noted in my written statement, the Apollo-Soyuz mission during the 1970s helped build a level of trust between the United States and the Soviet Union, and laid the foundation for very successful bilateral civil space cooperation with Russia in the 1990s.

- That said, there are certainly risks associated with cooperating with China. For example, the Chinese civil space program is controlled by the military. Therefore, there is a real possibility that any bilateral cooperation could contribute to China's military space programs. However, I am confident that we can identify discreet, cooperative projects that would not pose any significant risks to US national security. Indeed, if we were able to cooperate with the Soviet Union on space during the height of the Cold War in the 1970s, we should be able to find ways to cooperate with China today.

Space infrastructure and workforce development by others nations.

- Foreign states increasingly recognize the growing importance of outer space and are devoting significant resources into the development of their space infrastructure and workforce. Indeed, approximately 60 nations and government consortia, as well as numerous commercial and academic satellite entities, operate satellites. The most authoritative, unclassified resource on global space developments is *The Space Report: The Authoritative Guide to Global Space Activity*, which is published annually by the Space Foundation.

Congresswoman Haley Stevens

Discovery and stockpiling of Rare Earth Elements.

- Unfortunately, I don't believe that I have the appropriate background or knowledge to effectively answer this question.

Congressman Troy Balderson

Improving workforce development in the science and space exploration fields.

- While I do not have significant experience in this area, I believe it is critical to establish programs at the elementary, secondary, and college-level that create an effective pipeline for individuals interested in working in the science and space exploration fields.

Congressman Bill Foster

Nuclear power for space travel

- Unfortunately, I don't believe that I have the appropriate background or knowledge to effectively answer this question.

Appendix II

Additional Material for the Record

DOCUMENT SUBMITTED BY REPRESENTATIVE BRIAN BABIN

wsj.com

Navy, Industry Partners Are 'Under Cyber Siege' by Chinese Hackers, Review Asserts

Gordon Lubold and Dustin Volz

10-12 minutes

WASHINGTON—The Navy and its industry partners are "under cyber siege" by Chinese hackers and others who have stolen national security secrets in recent years, exploiting critical weaknesses that threaten the U.S.'s standing as the world's top military power, an internal Navy review concluded.

The assessment, delivered to Navy Secretary Richard Spencer last week and reviewed by The Wall Street Journal, depicts a branch of the armed forces under relentless cyberattack by foreign adversaries and struggling in its response to the scale and sophistication of the problem.

Drawing from extensive research and interviews with senior officials across the Trump administration, the tone of the review is urgent and at times dire, offering a rare, unfiltered look at the military's cybersecurity liabilities.

The 57-page document is especially scathing in its assessment of how the Navy has addressed cybersecurity challenges facing

its contractors and subcontractors, faulting naval officials for failing to anticipate that adversaries would attack the defense industrial base and not adequately informing those partners of the cyber threat. It also acknowledges a lack of full understanding about the extent of the damage.

"For years, global competitors, and adversaries, have targeted and breached these critical contractor systems with impunity," the audit says. "These enterprises, regardless of their relationship with the department, are under cyber siege."

The Navy declined to comment on the review, which hasn't been publicly released.

Chinese officials didn't immediately respond to a request for comment, but in the past have denied engaging in cyberattacks.

The review presented the threat posed by China in particularly stark terms, arguing that its cyber espionage operations against the U.S. military, its suppliers and the private sector in general have shifted power dynamics between the world's two biggest economies.

China has "derived an incalculable near- and long-term military advantage from it [the hacking], thereby altering the calculus of global power," the report said.

The findings are of acute interest and concern within the Navy.

"We are under siege," said a senior Navy official. "People think it's much like a deathly virus—if we don't do anything, we could die."

John Hultquist, director of intelligence analysis at the U.S.-

based cyber firm FireEye , said the hacking "appears to be preparation for great power conflict."

Mr. Hultquist, whose firm has closely tracked China's targeting of the Navy and maritime technology, added: "If you are a Navy leader, you have to see that these are the tools they could use to fight us decades down the road."

FireEye last week renamed the Chinese hacking group believed to be behind the attacks on Navy contractors and research universities, from Temp.Periscope to Advanced Persistent Threat 40, or APT 40, a rare designation the firm reserves only for the most sophisticated hacking squads it has high confidence it has correctly identified.

One major breach of a Navy contractor, reported in June and attributed to Chinese hackers, involved the theft of secret plans to build a supersonic antiship missile planned for use by American submarines, according to officials.

The hackers targeted an unidentified company under contract with the Navy's Naval Undersea Warfare Center in Newport, R.I.

Coupled with that breach, a second breach last year prompted Mr. Spencer to request the internal review, Navy officials said.

The report repeatedly singles out China and Russia in the theft of military secrets, portraying their actions as calibrated to achieve strategic objectives while remaining below the threshold of armed conflict, a metered approach that the U.S. has struggled to defend against.

The review found flaws with the Navy's longstanding approach

to its own supply-chain security, which relies on contractors self-reporting vulnerabilities and breaches. "That after-the-fact system has demonstrably failed," the review said.

According to U.S. officials and security researchers, hackers have stolen highly classified information about advanced military technology. Victims of Chinese attacks alone span large and small contractors, major universities that develop maritime technology and receive billions in federal research dollars, and the Navy itself.

The Navy and Defense Department "have only a limited understanding of the actual totality of losses that are occurring" due to a scarcity of resources and difficulties involved in tracking breaches at contractors and subcontractors, the report said.

"Only a very small subset of incidents are 'known' and of those known, an even…smaller set are fully investigated," it said.

The report is unclassified and doesn't provide specific details about individual breaches or tally recent intrusions. A separate classified document details some of the known breaches of the Navy or its contractors.

Navy officials declined to give even an estimate of incidents over the last 18 months other than to say they were "numerous."

China is considered the biggest thief, officials said, but Russia is another source of concern. Iran also has breached Navy systems, an official said, but that occurred before the Trump administration, the official said.

"It's not only the number of breaches but the magnitude of the

loss that is so troubling," said another Navy official.

When contractor breaches are investigated, information about the attacks "is often hyper classified and difficult to share, sometimes leading to an alarming lack of understanding and appreciation of the threat," the review said.

The top-to-bottom review of the Navy's cybersecurity began last October. The Wall Street Journal reported in December that the review was ordered by Mr. Spencer after a series of hacking incidents.

The Journal reported last week that Chinese hackers had targeted and potentially compromised more than two dozen universities in the U.S. and around the globe as part of an elaborate scheme to steal advanced maritime technology secrets. Some of the schools, such as Penn State's applied research laboratory, are under contract to the Navy.

In response to those revelations, Sen. Edward Markey (D., Mass.) sent letters Tuesday to Acting Defense Secretary Patrick Shanahan and Homeland Security Secretary Kirstjen Nielsen asking questions about how their agencies protect research institutions from cyberattacks.

"In the era of great power competition, it should come as no surprise that Chinese hackers are targeting academic institutions ripe with valuable information about U.S. military capabilities," Mr. Markey wrote.

The Navy review faulted the military branch's culture as lacking an appreciation of the cybersecurity threats it faces, being unable to anticipate novel attacks and favoring compliance and

governance over outcomes.

Among recommendations, the review urged identifying and better protecting essential data, selecting leaders to oversee a long-term cybersecurity strategy and installing new accountability measures on contractors to ensure they meet cybersecurity standards.

The national security implications of China's cybertheft of advanced research from Navy contractors and universities are considered so severe that the issue has been mentioned in the presidential daily brief on multiple occasions, according to a person familiar with the matter. Some subcontractors have been breached by the same Chinese hacking group several times within the same year, despite warnings from investigators, the person said.

The Trump administration has sought in recent months to hold Beijing responsible for what officials have described as a relentless onslaught of intrusions into U.S. corporate and government networks. Chinese hackers stand accused of stealing hundreds of billions of dollars annually in intellectual property from U.S. businesses, and the Justice Department in recent months has announced a series of charges that have blamed Beijing for a variety of wide-ranging cyberattacks.

Key Takeaways from the Review

The Navy report's authors conducted 31 site visits and interviewed 85 current senior military officers and civilians across both the Navy and wider Defense Department, as well as

senior officials at the Federal Bureau of Investigation, Department of Homeland Security and White House National Security Council, among others. Here are their main conclusions:

- The Navy and its industry partners are facing relentless cyber attacks that seek to steal sensitive national security data by a wide range of foes, with China and Russia the most adept and strategic.
- The U.S. is at risk of losing global military and economic advantages due to cyberthefts of secrets and intellectual property.
- Despite efforts to address the problem, the defense industrial base has suffered "a flood of breaches of significant data" and "continues to hemorrhage critical data."
- The Navy and Defense Department have only a limited understanding of the totality of losses they and their partners are suffering.
- The Navy is focused on "preparing to win some future kinetic battle, while it is losing the current global, counter-force, counter-value, cyber war," the review's authors conclude.

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